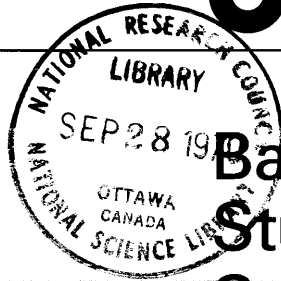


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Background Study for the Science Council of Canada

1970
Special Study
No.12

Aeronautics-
Highway
to the Future

By J.J.Green

ANALYZED

Aeronautics- Highway to the Future

A Study of Aeronautical R & D in Canada

ANALYZED

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Foreword

A Special Study on Aeronautical R & D in Canada has now been completed for the Science Council of Canada by Dr. J. J. Green and his colleagues* who have prepared the report which is published in this volume.

During the period that Dr. Green's Committee was at work, an in-house task force was also in operation within the Department of Transport which was seeking to redefine that department's goals and objectives and to regroup the department's resources to work effectively towards the achievement of these goals. The results of the work of this departmental task force are now public and it appeared opportune for the Science Council to express its views on those organizational matters which are important to the future of aeronautical R & D, and the aeronautical industry in Canada, so that due consideration can be given to them during the process of organizing the new Ministry of Transport. These views of the Science Council are expressed in this Foreword, rather than in a separate publication, since the background material is fully documented in the accompanying special study report.

The study on aeronautical R & D was first proposed in a letter dated May 6, 1968, to the Chairman of the Science Council from Mr. J. R. Baldwin, who was at that time Chairman of the National Aeronautical Research Committee. This letter contained the following paragraphs:

"Over recent months the members of the National Aeronautical Research Committee have been exchanging views with regard to the duties and role of that Committee, while the Technical Advisory Panel under NARC has at several meetings engaged in discussions on the general subject of aeronautical research in Canada and the functions of the Panel. Both groups believe that not only is a re-assessment needed but some changes in machinery and organization are likely to be required. In the years since the NARC was established, great changes have taken place in both civil and military aviation, in the supporting industry, in the position of research, and in government policy objectives and legislation affecting all these fields.

*Those who participated in the study are identified in Appendix 2.

"At its last meeting the National Aeronautical Research Committee came to the conclusion that it might itself be an appropriate body to advise on the machinery for the implementation and co-ordination of a National policy, but that any decision on structure and organization must depend in large part on a re-definition of national objectives for aeronautical research and development in Canada. It was noted, moreover, that a review of this subject would in fact be a corollary to the review which has already been undertaken with regard to the related field of space research.

"In the circumstances the Committee has asked me to indicate to you its desire that the Science Council undertake a review of aeronautical research and development in Canada. It was suggested that this might centre upon the following points:

"1. Current and anticipated military and civil aeronautical research and development in Canada in both the public and private sector.

"2. The changes which have taken place in government policy objectives and legislation, in technology, and in the role of aviation at the operating and industrial support level, including the relationship between the aeronautical and space field.

"3. The desirable goals for aeronautical research and development in Canada, taking into account both domestic and international policy objectives, industrial potential and the economic implications of industrial development.

"4. The desirable role for the public and private sectors in support of these goals."

The report which follows has drawn attention to the essential roles which aviation and the aircraft manufacturing industry have played, and are expected to play, in the development of Canada and its resources. The manufacturing industry has met many of our national defence requirements. It represents a high technology industry and it has generated, in recent years, a growing export trade. It has formed an important support base for aircraft operations in Canada. Aviation is vital to the existence of Canada as a nation providing a rapid transportation link between our own major but widely separated population centres and to important centres in other countries. It often provides the sole means of transport into many of our remote areas and an effective instrument for survey

and exploration, for mapping and for resource-oriented activities.

The present time is most critical for the aircraft manufacturing industry and it is evident that the government must very shortly arrive at a policy decision regarding the future of this industry. The Science Council's considerations are predicated on there being a firm government policy to maintain a healthy and viable aircraft industry to satisfy the requirements of national defence, air transportation and the development of our national resources.

The history of the aviation manufacturing industries in Canada—airframes, aero-engines and avionics—as described and documented in the background report, reveals their very heavy traditional dependence on defence orders from both Canada and abroad. A significant problem for these industries in the future will be the maintenance of their competitive positions in the face of a changing pattern of markets in which the defence component is likely to be markedly decreased.

The key question, which has been faced in this study, is that of finding an appropriate mechanism for providing advice to the federal government on the co-ordination of aeronautical research and development in Canada in both the civil and military fields; the very real difficulty lies in the fact that the government's interests in aviation are divided between a number of separate departments and agencies. The problem is further complicated by the fact that support for the aeronautical industry is important not only because of Canada's need for air transportation, but also because the industry is important—as a high-technology industry—to the country's economic development.

The report which follows makes and documents the case for the immediate establishment of an Aeronautical Research and Development Board, to replace the existing National Aeronautical Research Committee; the principal task suggested for the Board is that of providing on a continuing basis a co-ordinated and future-oriented view of Canada's requirements in aeronautical R & D in line with the perceived trends in the development of aviation in the service of the country.

The Science Council agrees with the report and considers that such a Board should be set up, with adequate provision being made for the representation of the public and private sectors and of the universities. The

members chosen from the Public Service should be selected from the Department of Transport (civil aviation), the Department of National Defence (military aviation), the National Research Council and the Department of Industry, Trade and Commerce. Those members from the private sector should include representation from the airframe, aero-engine, avionic and air transport industries. The university members should represent the aeronautical research community, including aviation medicine and "human engineering". The members of the Board, which might consist of about 12 members, should be chosen for their breadth of experience, knowledge and understanding of aviation, together with their current responsibilities in this field.

Such a Board should have at its disposal wide consultative mechanisms; such could be ensured by having the existing Technical Advisory Panel, which at present supports the National Aeronautical Research Committee, continue to serve and by having it report to the new Aeronautical R & D Board. The Technical Advisory Panel could profit from expanded membership, including stronger representation from the various sections of the aviation industry and from the universities. It will be important that specialists in aviation medicine and flight safety be appointed to the panel. The system of associate committees, which at present supports the Technical Advisory Panel but which are administered by the National Research Council, should continue to serve, at the discretion of that Council, and as required by the challenging areas of aeronautical science and technology important to Canada.

In the past, one of the most important defects of the National Aeronautical Research Committee has been that no minister has been responsible for receiving its advice or for ensuring that the advice given by the associate committees and the Technical Advisory Panel has been accorded adequate consideration. To correct this situation, the Science Council recommends that the new Aeronautical Research and Development Board should be made directly responsible to the Minister of Transport. This advice is offered after a close examination of a number of alternative ways or avenues through which the Board's advice can be brought to the attention of the government; the final choice of the Minister of Transport was made with due regard for the importance of air-

craft operations in Canada and the very great part which aviation has played and will play in the growth and development of this country. Nevertheless, the Council recognizes that the Minister of Transport will need the co-operation of his colleagues in implementing the advice of the Aeronautical Research and Development Board because of the division of responsibility in aviation matters among several Cabinet Ministers.

The creation of such a board at this time may, on the surface, appear anomalous. The reorganized Ministry of Transport will encompass many bodies including a Transportation Development Agency and it is to be hoped that this agency will be provided with access to external advice through some widely constituted Transportation Advisory Board or Committee. Why, then, is there a need for a separate Aeronautical R & D Board? The answer lies with the great difference between, on the one hand, the level of advancement of Canadian expertise in aeronautical R & D which has substantial achievements to its credit, and on the other, the fledgling nature of much of the R & D activity involved in other transportation modes. When, in the future, research on these other modes achieves the same level of sophistication as that in the aeronautical field at the present time, it will be time to consider merging the Aeronautical Board with the larger body.

In the long term, it may one day be advisable to transfer responsibility for the existing National Aeronautical Establishment to the Transportation Development Agency. However, experience has shown that it takes several years to develop a headquarters staff with the competence to supervise successfully the complex technical program of an organization such as the National Aeronautical Establishment; consequently, such a move should not be made at present. It would, however, appear logical for the National Research Council to merge, administratively, the section of its Division of Mechanical Engineering concerned with aircraft power plants with the National Aeronautical Establishment, to concentrate all of that Council's major aeronautical activities within a single unit.

The R & D facilities at the National Aeronautical Establishment should be employed for the long-term benefit of Canada and our manufacturing activities. With this in mind, the projects which are initiated by the Establishment itself or in response to the advice

of the Aeronautical Research and Development Board should look at least 10 years into the future to the kinds of problems and possibilities which will be open at that time to our manufacturers and aircraft operators in the civil sector in particular—in sharp contrast with the shorter range projects in which the Establishment is presently engaged. In general, the members of the Establishment should work more closely with the aviation industry in such programs, than has been the case to date, and the relations between the Establishment and the industry which have been fairly good in the past should be strengthened. For its part, the industry must ensure that it makes its views known to the Establishment either directly or through the Aeronautical Research and Development Board.

It seems likely that future aeronautical R & D activities in this country may be related more to civil aviation than to the needs of the defence sector. Dr. Green's Committee was unable to obtain fully detailed information on the long-term planning of the Department of National Defence and therefore was not able to assess in detail the aviation needs of the defence sector in the years ahead. The assessment of aviation in Canada in the future, as it is discussed in the report, must therefore be considered to represent an informed assessment of civil requirements and a reasonably construed assessment of the likely military requirements.

The results of the study indicate that the most challenging avenues open to Canadian manufacturers of complete aircraft appear to be based on their existing and potential capability to design and develop STOL aircraft systems. One of the first tasks of the Aeronautical Research and Development Board should therefore be to make technical, economic and market assessments of the current STOL and v/STOL development projects in the Canadian aircraft industry. Assessments should also be made of those new concepts and techniques which promise significant advances in the state-of-the-art. For the longer term, the establishment of a parallel program of research and development in commercial v/STOL aircraft as a total system appears attractive, subject again to analysis by the Board. This could bring into focus the R & D efforts of the government, university and industry sectors in accomplishing a national objective which could eventually make a major contribution to Canada's technologi-

cal progress, industrial competence, transportation efficiency and export market potential. Similarly, in the aero-engine field, consideration ought to be given to enlarging and accelerating the existing program of research, design and development of small- and medium-thrust engines as a high-priority objective.

There have been important developments in the avionic and aircraft accessory fields throughout the world since the end of the war and Canadian manufacturers have been quick to take advantage of opportunities in this field. Such opportunities should increase in the years immediately ahead and Canadian manufacturers should be given every opportunity to extend their activities in the laboratory and in the marketplace because, unlike the market for complete aircraft, there are likely to be fewer disincentives to the participation of Canadian companies in the supply of complete avionic and accessory systems or subsystems on a worldwide basis. The new Aeronautical R & D Board should ensure that particular attention is given to research and development work in support of avionic and accessory manufacturers.

An important element in the total chain of activities which together can lead to the production of new aircraft is flight testing and evaluation. Most of this activity, naturally, is concentrated in industry. However, government as a major procurer of aircraft has in the past maintained an independent capability in this field. The need for this capability is expected to remain valid in the years ahead and so steps should be taken to ensure that this role is fulfilled efficiently and that existing expertise is used to maximum benefit. The Aeronautical R & D Board could be invited to review this activity in government with a view to ensuring its continued health.

There is a continuing and growing need for aeronautical R & D in support of air operations, as distinct from aircraft manufacture. This need will be considerably increased when thought is given to introducing commercial supersonic aircraft into Canada's airways.

Aviation medicine, for which Canada once had an excellent reputation, should be a subject of more concern than is accorded to it today. Many problems in both civil and military aviation demand attention. It would appear that Canada should seek to maintain one, but not more than one, well-supported

research group in this area.* Such a group should draw upon existing competence where this is to be found; the appropriate location of such a group should be the subject of advice from the Aeronautical R & D Board, but close ties with a university would be advantageous.

University participation in aeronautical research and development should be an important part of the overall Canadian effort. In the past, universities have often had to seek funds for research from foreign sources and there may continue to be certain special cases in which this is desirable. In addition, many of the aeronautical graduates of Canadian universities have sought employment abroad. While the report offers no easy prescription for ensuring that university aeronautical research activities are optimized with respect to Canadian needs or with respect to the employment of graduates in Canada in larger numbers, the whole question of university participation in this field appears to hinge on support being given by government agencies and by industry. Only with adequate support from Canadian sources will the universities be able to focus their aeronautical activities on problems of domestic importance.

The Aeronautical R & D Board must be concerned with the extent to which aeronautical R & D should be divided among Canada's universities. University research centres specializing in aeronautical studies—such as the University of Toronto's Institute for Aerospace Studies—which have reached, or can soon reach, the critical size for effectiveness should provide the firm basis of competence upon which rational expansion should be planned. However, means should also be devised for the encouragement and support of new and potentially viable groups of researchers outside the existing centres, where such are justified. For both the centres and the new groups, the detailed problems of funding research and providing material support will require to be worked out in co-operation with the various granting agencies and laboratories.

**Note added in press:* Since this Foreword and report were written, it has become known that the Department of National Defence will establish, during the summer of 1970, a Canadian Laboratory of Environmental Medicine by the amalgamation of the Defence Research Establishment Toronto and the Institute for Environmental Medicine.

Once again the need in Canada for improved research co-operation between the universities, industry and government must be reiterated. The Aeronautical R & D Board should examine ways in which individual research projects may be more closely linked and structured to involve the laboratories and staffs of all three sectors. The universities will have new and important roles to play in the improvement of their present tenuous relationship with industry in particular. Some of them can today offer proven research capabilities; they must all in future demonstrate a keener interest in and appreciation of the problems facing manufacturers and operators in the aviation business. In the last analysis, there need be no conflict between the interests of research scientists at the universities and the long-term needs of aviation. And, over and above this, Canadians must look to the universities in the first place for the kinds of expertise in their graduates which will be important in the longer run to the country as a whole.

O. M. Solandt,
Chairman,
Science Council of Canada.

Acknowledgements

As Chairman of the Science Council Study Committee on Aeronautical Research and Development in Canada, I wish to thank Mr. J. T. Dymont and Dr. A. J. R. Smith who, with me, were members of the Study Committee. I also wish to thank those members of the full Committee who were appointed as advisers but who nevertheless bear no responsibility for the statements of opinion and conclusions reached in this report. The background information supplied by the Science Council Committee members and the advisers constitutes a major portion of the material on which this report is based. I am most grateful to my colleagues for the provision and discussion of this basic information.

To all those individuals and organizations who provided written or verbal information and those who willingly gave of their time to discuss with me and my colleagues the various aspects of the Committee's interests, I extend my sincere thanks.

I wish particularly to record my deep appreciation for the extensive and significant co-operation and assistance rendered to me by Mr. A. H. Wilson of the Science Council's staff. Mr. Wilson joins me in thanking Mr. D. Hunka and Mr. J. Mullin, also of the Science Council's staff, for the generous assistance rendered to the Committee at all times. In the arduous task of preparing the manuscripts through their successive stages Mrs. Gwenn Fulford and Miss Beverly Wood provided very extensive service which is gratefully acknowledged.

J. J. Green

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Chapter I

Introduction

At its thirteenth meeting in June, 1968, the Science Council of Canada agreed to comply with a request from the National Aeronautical Research Committee (NARC) to undertake a study of aeronautical research and development (R & D) in Canada which would give particular emphasis to the problems of organizational structure and policy formulation.* Dr. J. J. Green subsequently agreed to become Chairman of the Science Council Committee to undertake this study, and Mr. J. T. Dymont and Dr. A. J. R. Smith were appointed to assist him. With the concurrence of the Council, a number of people from both public and private sectors were asked to act as advisers to the Committee and to assist it with the collection and discussion of background information. The Science Council also assigned two of its staff to assist Dr. Green and the Committee.†

Terms of Reference

Based on the original NARC request and on subsequent discussions during the summer of 1968, the following terms of reference for the Aeronautical R & D Study were written by Dr. Green and approved by the Science Council at its September meeting:

"The Science Council Study on Aeronautical Research and Development in Canada should examine in breadth the current activities within the country and their relationship to the present and probable future situation pertaining to aeronautics in Canada, both military and civil. An attempt should be made to forecast the desired evolution of aeronautical research and development facilities to meet our requirements. In order to optimize the cost-effectiveness of our research and development, the Study should recommend an organizational and management system to ensure the tightest co-ordination between the research and development facilities on the one hand and the requirements on the other."

*Additional details with regard to the NARC request and the subsequent steps taken to set up the study have been given in the Foreword by the Science Council of Canada.

†A full list of those involved and their current affiliations is given in Appendix 2.

Objectives of Study

It was intended, when this concise statement was first prepared and accepted, that the Committee would be free to make a very broad study of all aviation activities going on in Canada at the present time. Speaking generally, these activities fall roughly under three headings—manufacture, operations, and research and development. The Committee was interested in finding out what relationships exist between these three activities, what their significance is in meeting the present needs of the country and what role they might play in the future in contributing to economic growth and social gain. It is clear that the last activity—aeronautical research and development, which is at the heart of this Study—is pursued or should be pursued in support of the first two activities. The Committee was most anxious to find out how effectively this was being done and, if possible, to erect some signposts to guide the evolution of this activity in meeting the larger and perhaps more diverse requirements of the future. It was assumed at the outset, and nothing emerging from the study has suggested otherwise, that the way in which a country organizes its R & D efforts is an important factor in the effectiveness of these efforts, particularly where they must be mission-oriented, as they are in this case—to support the activities of aircraft manufacture and operations. For this reason the Study Committee tried to keep in mind at all times such questions as organization and advice, management and utilization of all available facilities, co-operation and the exchange of information.

The Committee's objective in studying the manufacturing industry was to achieve a broad picture of the overall magnitude of the manufacturing activity in terms of annual sales, exports, employment and a more in-depth feeling for its quality and diversity of products, its strengths and weaknesses, its interdependencies both national and international, its overall structure—viewed as an entity—and its contributions to aircraft operations in Canada. Since the picture is far from static we wished to see how the industry was reacting to change and what its future might be.

Turning to the second activity—operations, the Committee set out to examine the current state of both our military and civil aircraft operations, including their type, extent,

diversity and quality. A brief review of world aviation was made to give some perspective to the Canadian scene. Here again we were looking for trends and the influence of change but more particularly we tried to get a feel for the relative importance of aircraft operations in Canada and their past and likely future significance in the development of this country.

With regard to aeronautical research and development, it was essential that we examine the *total* picture insofar as the financial statistics available to us would permit. Of more importance, however, was a qualitative review of the kinds of major projects that are going on in the three sectors—government, industry and university. We agreed also that we should look at the kind of federal government co-operative programs which the aircraft industry is utilizing in its R & D activities and how the universities are procuring their much-needed financial assistance for aeronautical research programs.

After having gathered this information, the next step was to examine the government's advisory structure concerning aeronautical R & D, and how aeronautical research and development is organized and co-ordinated in support of the manufacturing and operating activities. This particular subject has two aspects. First, how does the government co-ordinate its own departmental activities in aeronautics? Second, how is the total Canadian effort in aeronautical research—in the universities, government and industry—co-ordinated or integrated for tackling problems, particularly the major problems, encountered in the manufacture (design and development) and operation of aircraft in Canada? The Committee, mindful of the reason for its own existence, examined carefully the current organization and analysed its strengths and weaknesses.

The next stage of the study was a look into the future. Again, to give perspective to the Canadian scene, our first look was at the probable future of world aviation, military and civil. Canadian aviation in the next decade into the future, from the point of view of operations (military and civil) and aircraft manufacture, was to be broadly examined and lessons and signposts were to be identified whenever possible.

The Committee expected that this examination of the future would reveal the sort of opportunities which might be attractive to

aviation in Canada in the years ahead, and which would call for aeronautical research and development. We envisaged the possibility that there might be more aeronautical tasks ahead than we had resources and facilities to cope with. It was therefore considered important to develop a set of guidelines which could assist in identifying those R & D tasks which offered the best potentials. After this we looked forward to the likelihood of our being able to discuss or at least to indicate some actual aeronautical research and development programs of the type which should be receiving emphasis at this time or in the near future. Finally, with an eye to future needs rather than past mistakes, we knew that we must give much thought to the problem of improving the organization for providing advice and management for aeronautical research and development in Canada—a framework in which technological needs and opportunities can be recognized and exploited by industry with government encouragement and co-operation.

Definitions and Concepts

In its first science policy report, the Science Council included definitions of the terms *basic or fundamental research, applied research, development and innovation*.^{*} These definitions have been adopted for the purposes of this report. They have been set out in full in Appendix 3.

Since aeronautics is an applied science, this report is principally concerned with applied research and development activities and with opportunities for the application of new knowledge resulting from these activities in Canada. As indicated above, our work was not concerned solely with aircraft and their propulsion systems but also with the manifold problems of aircraft operations and their need for research and development. We omitted from our considerations airborne weapon systems, aerospace equipment associated with satellites and rockets, air cushion vehicles, and the problems of airport terminal buildings.[†]

^{*}Science Council of Canada. Towards a national science policy for Canada. Report No. 4. Ottawa, Queen's Printer, 1968. 56p.

[†]This report, therefore, does not duplicate work done by J. H. Chapman and his colleagues for the earlier study, *Upper Atmosphere and Space Programs for Canada*, published in February 1967 as the Science Secretariat's Special Study No. 1.

For the purposes of this report, the Committee's main interest was concerned with the following seven specific areas of aeronautical activity:

1. *Aircraft structures*, including the design, development, and testing of load-bearing aircraft components and parts;

2. *Materials*, including the establishment of specifications, processes, and testing techniques for the adaptation of natural and synthetic materials to the needs of aircraft structures, systems and equipment, and avionics;

3. *Aerodynamics*, including the investigation, measurement and prediction of the characteristics of fluid motion and especially those of reaction with bodies in motion through the atmosphere which make flight possible; the direct and indirect assessment of loads on aircraft structures and power plants; the search for means to augment the lift and control reaction of vehicles sustained by the atmosphere and for means to counteract the noise sources associated with vehicle reactions; and the study of aerothermodynamic and aeroelastic phenomena;

4. *Aircraft propulsion*, including the design, development and testing of aerothermodynamic devices which propel aircraft through the atmosphere; the study of mechanical components incorporated in the devices; the search for fuels and lubricants to enhance these devices; and the study of noise sources related to the momentum reaction of the atmosphere;

5. *Systems and equipment*, including the design, development and testing of the mechanical, pneumatic, hydraulic and electrical systems of aircraft; the design, development and testing of airborne electronic equipment; and the design, development and testing of aircraft support equipment for ground handling, training, maintenance and ground-based navigation facilities*;

6. *Aviation medicine and "human engineering"*, including the adaptation and integration of human beings into aircraft systems; the optimization of systems, equipment, controls, and airborne aids to the advantage of the crew; the psychological and physiological limitations of the human being in the operating environment of aircraft; and the search for means to condition the human being for advanced aircraft systems and their potential emergencies;

7. *Aircraft operations*, including the planning, selection, flying, navigation and hazard

analyses associated with such operations and embracing the influence of weather; and the training of flight personnel.

Organization of the Study

The members of the full Study Committee met together for the first time on November 4, 1968, and met again six times during the next twelve months. The early meetings were principally concerned with the strategy, content and organization of the study and the later ones with discussion and evaluation of prepared background material. Subgroups of the Committee charged with specific tasks met from time to time throughout this period.

The background material for the study was prepared by the individual members of the Study Committee according to their respective interests and experience. No questionnaires were designed especially for the study. Instead, the currently available statistics—updated where possible—were put into order according to the specific needs of the study and additional information was sought only when gaps were identified.†

Further inputs were invited from those industrial, professional and other associations with interests in aeronautical research and development. A list of the associations which responded to the invitations is given in Appendix 4, together with a list of unsolicited responses. The letters of invitation to the associations from the Chairman of the Study Committee explained what might be called the "strategy of the study", which we set out in three consecutive stages, as follows:

1. The identification of Canadian and foreign needs, opportunities and problems that will arise in the foreseeable future, and that are germane to the civil and military aspects of the manufacture and operation of aircraft and their associated systems by public and private agencies and companies in Canada.

*The electronic equipment included under *systems and equipment* may be referred to in parts of this report as *avionics*.

†For background material, the Study Committee also had available a number of recent publications and papers in the subject area; for example, a report on *Civil Aviation Research & Development: An Assessment of Federal Government Involvement*, prepared by the Aeronautics and Space Engineering Board of the U.S. National Academy of Engineering, and the first two volumes of the report by the Department of Industry, Trade and Commerce on its study of the Canadian Aerospace Industry.

2. The identification of major objectives for future aeronautical research and development activities in Canada which are related to (1) above, which reflect the strengths of the current Canadian institutions and facilities for work of this kind, and which emphasize the adoption of the systems approach to the problems of program design.

3. The identification, at the national level, of an institutional structure that will be more appropriate than the present one for the continuous co-ordination of future aeronautical research and development activities in this country.

It was made clear that the Study Committee wished to have the *views* of the associations rather than detailed briefs.* We suggested to the associations that these views should cover the following principal areas:

1. The kinds of programs in aeronautical research and development that might be done in Canada to contribute to economic growth, scientific or technical knowledge, with an assessment of facilities and manpower required for such programs.

2. The kind of interrelationships that should be established between government, universities and industry for the management and conduct of effective programs of aeronautical R & D.

3. The appropriate basis for international relationships in the field of aeronautical research and development and the relationships that Canadian programs and policies should have to those of the United States and other countries.

Representatives of the Study Committee also undertook a series of meetings and visits in Canada to discuss the problems associated with aeronautical R & D activities at a more personal level. The series included, for example, meetings with representatives of the Air Industries Association of Canada and visits to the aeronautical laboratories of the National Research Council and to representative firms in the Canadian aircraft industry. The Chairman of the Committee and the Project Officer also met with several experts in the United States and the United Kingdom, the two countries that have most profoundly influenced aeronautical research and development in Canada. A list of the visits and meetings is given in Appendix 4.

*Not all of the responding associations gave views of the kind suggested. Some recommended to their members that they respond individually.

Chapter II

Observations based on the History of Aviation

The terms of reference for this study require that current aeronautical research and development (R & D) activities in Canada should be broadly examined. They also require that the relationship between current and probable future activities in these fields should be examined, together with the question of the development of a co-ordinated and effective organizational and management system. On the basis that the past and present are—together—the springboard to the future, and since activities associated with aviation are international in character, it was thought desirable that the first step in the study should be to see how the activities in this country have developed during the 60-odd years of aviation history, against the background of events in those countries whose influence was most strongly felt in Canada. A review of this kind was made, and has been included in this report as Appendix 1. From this review, it has been possible to make a number of observations which have relevance for future Canadian aeronautical R & D activities. These observations were discussed by the Study Committee and with other experts during the series of meetings and visits. These observations are as follows.

During the 66 years which have elapsed since the Wright brothers made their historic first flight, aviation has enjoyed phenomenal progress. This progress has not been easy, for at every stage of its development, aviation has been faced with formidable obstacles. The elimination of these obstacles and the high rate of progress have been achieved through research and development. Aeronautics has had the benefit of a massive research effort, undertaken primarily in government laboratories, but also in universities and industry. Accompanying this research work, and relying on its results, has been an intensive development of aircraft by industry and the users, often undertaken with government financial assistance or under government contract. This combination of aeronautical research and development has absorbed vast sums of money, probably more so than in any other field of scientific endeavour, the bulk of which has assuredly been expended by governments. Sir Richard Fairey estimated that between the Wright brothers' flight and 1948, the total expenditure by all countries was the equivalent of \$256 billion (U.S.).*

Throughout most of the history of aviation the major emphasis in aeronautical research

has been the support of military aircraft development. Within the first decade of mechanical flight, the French government, followed by others, concluded that aircraft would play a useful military role. It has been, over the years, this growing recognition of the military value of aviation which has led governments to play such a leading role, both in the provision and operation of aeronautical research facilities and in the financial support for aircraft development within industry. The maintenance of the momentum of aeronautical development, particularly in the direction of the main stream, will call for continued heavy expenditure in which a significant role will undoubtedly continue to be played by governments.

The progress of aviation has been smooth and successful when it has been subject to good planning and undertaken as a co-operative effort between government and industry. Under such circumstances aeronautical research and development, which are the most significant factors, become most productive. Since aeronautical research is an applied science it must be mission-oriented. To ensure that it remains so, in countries such as Britain and the United States, it is considered of paramount importance that aeronautical research in government laboratories should be closely co-ordinated with the current and future needs of aviation and specifically of the aircraft industry, in its role of designing and developing successive generations of aircraft. In Britain, this has been attempted by having the aeronautical laboratories of the government under the same ministry responsible for the government's administration of aircraft design, development and procurement contracts in industry. In the United States, a committee (the National Advisory Committee for Aeronautics) appointed by the President was responsible for the broad program of aeronautical research in government establishments; the committee members were aeronautical experts from industry, the armed services and universities. In Britain there exist arrangements for maintaining a good liaison between universities engaged in aeronautical research, the scientists in government laboratories, and, to a degree, the engineers in industry. This has kept the

*The 1950 Wilbur Wright Memorial Lecture. The Journal of the Royal Aeronautical Society. London, England, July, 1950.

university specialist in touch with the problems which impede aviation development and has provided the aeronautical scientist in government with a link to the more basic research conducted in the university. A weakness in technological and managerial follow-up has tended to offset these advantages.

Even with good planning and a tightly knit organization, the system does not always produce the best types of aircraft for the military or civil aircraft operators. This is particularly true in the case of civil aircraft where the involvement, sponsorship and overall control by government have generally been weaker than in the case of military aircraft. Industry itself, from time to time, has come forward on its own initiative with a private venture proposal which has resulted in the production of a new aircraft far superior to current types. In the United States where the free enterprise system has been most developed, the civil aircraft produced by the industry with minimum reliance on the government have been, on the whole, exceptional. The spur of competition and a close relationship in planning between the ultimate user and the industrial design team seem to be the prerequisites for successful aircraft development.

In earlier years, it was commonly accepted that civil aviation could survive quite adequately on those results from military research and development which were unclassified and appropriate to non-military application. This situation has changed very significantly in recent times. Civil aviation, particularly in the United States, has become big business. Because of the services it provides, and the involvement of government in its control and regulation, it is accepted that it also merits a primary access to the aeronautical research facilities operated by government.

Military aviation has been so conditioned to rely on aeronautical research that it unhesitatingly turns to the research laboratory for problem solving, improvements and the maintenance of excellence. Commercial aviation, in general, tends to live with its problems; conditioned to accepting compromises and dominated by economic considerations, it often has to accept changes more slowly and cannot itself afford extensive research programs. Its main course of action for problem-solving is through the aircraft manufacturer who is under pressure from the airlines to achieve improvements and

advances in each new generation of commercial aircraft to overcome any difficulties of the past. Because of its shortcomings as a good neighbour and the residual deficiencies in its performance of the services expected by the travelling public, commercial aviation will be subjected to increasing social pressures to improve its performance on both counts. Good teamwork between government and industry will be necessary to achieve progress in solving the problems.

As discussed briefly in Appendix 1, the constant demands for increasing performance and reliability from new aircraft types have exerted a profound influence on so many diverse industries and disciplines, with beneficial results thereto, that aeronautical research and development must be rated as one of the major contributors to a country's scientific and technical advancement. This in itself may be a further justification, in this day and age, for government support of aeronautics. This is no place to catalogue all the industries and disciplines which owe much of their growth and stature to aeronautics, but it is worth noting that the techniques of systems analysis and systems engineering, which were created to deal with complex aeronautical systems, are now being applied to problems as diverse as urban development, pollution control and ship-building. The entire space program of the United States is almost wholly based on the U.S. aviation industry and those government agencies established initially for aeronautical research purposes.

In the early years of aviation, advancement depended critically on basic scientific research. As our knowledge of aerodynamics, materials and structures has grown, there has been a far-reaching shift of emphasis to applied research, engineering and industrial development effort. This is not to say that basic research is no longer important; in aviation it is always desirable to gain significant operational improvements in new aircraft, over what is currently available; to do this, basic research may be necessary. The main stream of advance in the supersonic and hypersonic flight regimes has also called for more basic research. But the contemplation of a supersonic *Concorde* or a Boeing 747 *Superjet* is impressive for the sheer magnitude of the engineering design problems and the industrial effort involved.

The development process in both military and civil aircraft cases has been fraught with

great technical and financial difficulties. When completed, the new aircraft has had to meet or exceed its specifications. It has had to be outstanding in all important aspects in comparison with contemporaries. In times of rapid technical change this has been quite a challenge since 7 to 10 years may have elapsed between initiation of design and the placing of the new aircraft into service. The success of a new aircraft as an integral system is dependent on the matched excellence of its components—airframe, power plant, accessories and equipment. All countries, however competent technically, have experienced the frequent failure of such development projects. Aircraft have failed to meet the performance expected of them, or they have grown in weight to the extent that doubts have arisen about their potential. Or perhaps the role or the threat they were designed to meet had changed and they could not match it. If to any of these difficulties was added the more common one of escalation of costs, often far beyond what was originally estimated, then the project was in real trouble. One essential factor for success in these areas of aircraft development is a design team with demonstrated competence, and experience extending over many years.

Political considerations apart, the complexity and the cost of developing military combat and large civil aircraft have risen so much that it is increasingly difficult to justify their development in a country which offers only a small domestic market and an uncertain export market which is, in any case, highly competitive. International co-operation in development (as in the Anglo-French *Jaguar* and *Concorde*) has appeared attractive, for this provides for a sharing of development costs. It also assures a larger market in the case of military aircraft although not necessarily so in the case of advanced commercial aircraft.

In the dynamic world of today, aviation is vital to the integrity of Canada, providing a rapid transportation link between our linearly disposed population centres. This main airway system, and its accompanying regional system, complements a road and rail transportation network. In contrast, the northern expanse of Canada and the isolated communities east and west must rely almost entirely on aviation to supply their needs. In many places the aeroplane is the only known vehicle for the large-scale movement

of passengers and freight over large distances. The aeroplane has made it possible to patrol our forests effectively, to fight their fires, to assess their timber resources and to plan their harvesting. It has made an enormous contribution to the photographing and mapping of our vast territories, to exploring and prospecting for mineral wealth, and to studying and assessing our water resources.

Canada's national airline has grown to be one of the foremost in the world and one of the most respected. It has been a leader rather than a follower and has pioneered in many of the technical advances which have brought commercial aviation to its present state of efficiency. Our airline systems will no doubt continue to share the growth expected in succeeding years for all commercial air operations. We also enjoy an excellent record of accomplishment in using aviation in the roles mentioned in the preceding paragraph—transportation into the remote areas of Canada and the non-transportation roles of national development. There appears to be no reason why such operations should not continue to expand year by year into the future.

For a few years after the war the government adopted a policy that would meet military combat aircraft needs by fostering an industry capable of designing and developing such aircraft. But with the domestic market as small as it is, this policy became impractical in the light of the rising complexity and costs of such aircraft. The best that has been possible from an industrial viewpoint is to meet some of our military aircraft needs by Canadian production under licence from American aircraft manufacturers. Even this procedure is economically suspect unless a sufficiently large production run is obtained by securing additional orders from some foreign government. As regards civil aircraft, here again the government is not a heavy purchaser, and our airlines to be competitive have turned to foreign-designed aircraft to get the best available. Under the circumstances, only a portion of the domestic market, which itself is not very large, has been open to exploitation by our own aircraft industry. It is essential for survival that this industry should have an export market for its products. Experience here and elsewhere has shown that if every effort is made to design an outstanding aircraft to satisfy a domestic requirement, an export market for the product is most likely

to develop. By concentrating predominantly on the smaller, rugged, short take-off and landing (STOL) aircraft, particularly suitable for the Canadian environment, an important part of the industry has been able to maintain a design and development capability during the past 25 years. This has been economically successful because these aircraft have not only proved their utility in Canadian "bush" operations but have also found a ready acceptability all over the world.

In the aircraft power-plant field, Canada achieved a design and development talent covering the full range of powers. In the case of the large gas turbine, however, this talent was exposed to the direct competition of the very few major engine design companies of the world which are sustained by much greater resources and experience than we can muster. Canadian industry's survival in this field was unlikely. It is generally accepted also that it is more difficult for a country to develop and maintain a lead in this category of aircraft power plant without a matching competence in comparable airframe development, and this was lost when the *Arrow* was cancelled. On the other hand, by selecting the small gas turbine field, which is relatively devoid of powerful competition, and designing for excellence, the Canadian industry has been most successful.

Government participation in aeronautical research in Canada has followed the pattern established elsewhere and has largely been justified as a necessity for the support of national defence activities, but has been available to assist the civil aircraft industry in the development of new aircraft. Over the years, industry has indeed made very extensive use of the government research facilities. However, because the participation by the government in the administration of aircraft design, development and procurement has been intermittent, we have lacked the permanent organizational structure which in Britain or the United States has gone a long way to ensure that aeronautical research in government laboratories and in universities is closely co-ordinated with the current and future needs of aviation.

Canadian industry has been quite successful in building up a capability in the field of aviation electronics (avionics). Begun mainly to meet domestic requirements, the business has expanded to cater to a large and growing export market. The wide range of products

manufactured by the industry represents both native and imported technology. In the case of the former, Canadian forethought and ingenuity have led to direct innovation. In the latter case, Canadian talent has been able to add to the quality or reliability through engineering or production techniques. In the case of airframes and aero-engines, the evolution to increased size and complexity has faced the Canadian industry with a major problem. On the other hand, the developments in avionics have not presented insuperable problems to the Canadian electronic industry, nor do they appear likely to do so in the future. There appear to be no reasons why this industry should not be capable of remaining in the forefront.

Certain of the universities of Canada have engaged in the teaching of aeronautics and have expanded this into aeronautical research activities, rightly holding that for the graduate student experience in research is an essential part of the learning process. Through agencies such as the National Research Council (NRC) and the Defence Research Board (DRB), the federal government has assisted in funding much of this research work. By extending the research programs to subjects more typical of current U.S. interests than of the Canadian scene, additional funding support has, in certain cases, been attracted from U.S. government agencies. The result has undoubtedly been an enrichment of the graduate school programs but has encouraged the migration of Ph.D. graduates to the United States in search of challenging work more in keeping with their graduate training than that available to them in Canada. Fostering a closer rapport between industry and the universities could most likely resolve this particular difficulty, with mutual benefits.

Chapter III

World Aviation, 1969

In contemplating the present aspect of world aviation, it is convenient to treat the subject in two parts—military and civil, and to look first at military aviation since it has always been the trailblazer. While the world's second* supersonic civil aircraft, the Anglo-French *Concorde* is still in the flight test stages and has, at the time of writing, just exceeded the speed of sound, military aviation has had the benefit of 20 years of supersonic flight experience.

The gas turbine engine, which has made possible these high-speed operations, has increased in performance during the 20 years from about 5 000 lb. thrust at sea level to 47 000 lb. thrust. However, current military combat aircraft are using engines of between 16 000 and 26 000 lb. thrust, most of the outstanding aircraft having been designed in the mid or early 1950s and tailored to engines of less thrust than those available today. Generally speaking, relatively few military combat aircraft developments have been initiated during the last decade.

The typical single-engined fighter aircraft is small and compact, weighing between 13 000 and 30 000 lbs. fully loaded, and having a maximum speed between Mach 1.2 and 2.2. For example, the NATO F-104 Lockheed *Starfighter* and the MiG 21 which fly at Mach 2.0, weigh 28 000 lbs. and 17 000 lbs. respectively. Twin-engined fighters weigh upwards from 35 000 lbs. The McDonnell Douglas F-4 *Phantom* has a weight of about 57 000 lbs., while the General Dynamics F-111 weighs 77 000 lbs. Maximum speeds for these two aircraft are respectively Mach 2.2 and 2.5. The thrust to weight ratio of modern fighter aircraft usually falls between 0.5 and 0.7 and with so much power available, the attainment of good speed and rate of climb presents no great difficulty. Good handling characteristics and manoeuvrability are perhaps of overriding importance. Transcending these features, however, is the overall performance of the total weapon system of which the airframe and engine are but components, albeit important ones.

The modern fighter aircraft is a far cry from those of World War II. Its role has expanded beyond that of dog-fighting and bomber interception to include such duties as tactical support, strike and reconnaissance.

To carry out such multirole combat missions effectively, a variety of weapons and a range of avionic equipments barely dreamed of 25 years ago are employed. These include such items as airborne radar fire-control systems, inertial navigation systems, weapons release computers, radio altimeters, electronic counter-measures (ECM) equipment, sophisticated radio communication systems, and so on. A recent trend in military avionics has been to seek a true systems integration whereby all the airborne electronics are designed to meet overall system parameters to permit fulfilment of specified requirements and missions. This is a difficult assignment but the trend will undoubtedly continue into the future. The next step probably will be to centralize the computation functions of the avionics in a single airborne data-processor.

The development costs for fighter aircraft are very high and cannot be amortized by a return on the investment as is the case with commercial aircraft. The Avro *Arrow* development cost was about \$350 million. The British TSR-2 strike reconnaissance aircraft costs had reached \$720 million when it was cancelled in 1965 (nearly eight times the \$94 million estimated in 1958). Joint international programs such as the Anglo-French *Jaguar* trainer/tactical fighter, the European MRCA (multirole combat aircraft), which is now going ahead, and the Anglo-Australian trainer/possible strike fighter may be the pattern of the future. Experience suggests that such joint programs cost 20 to 50 per cent more than if handled by one country alone, but this still results in a significant overall cost saving for each partner. Some critics suggest that quality may suffer since in the past the most successful aircraft have been the products of a single design team. In any case the results from these early efforts at international co-operation will be watched with interest.

In these times of the intercontinental ballistic missile, bomber aircraft, more particularly the strategic bombers, occupy a debatable position. The 488 000 lb. subsonic B-52 of the United States Air Force Strategic Command first flew in 1951 and was on the drawing boards in the mid-1940s. The experimental B-60 and the much more recent Mach 3 B-70 did not progress beyond the prototype stage. The long-range bombers of the U.S.S.R. and Britain appear to be of nearly the same vintage as the aging B-52s.

*The Russian Tu 144 was the first supersonic transport to fly.

The United States Air Force is pressing for the development of the advanced manned strategic aircraft (AMSA), which has been a long-delayed contender to replace the B-52, but its future is still in doubt.*

A more important class of military aircraft is the long-range anti-submarine reconnaissance aircraft typified by the Canadair *Argus*, the Hawker Siddeley *Shackleton* in the United Kingdom, and its replacement the *Nimrod*, the Breguet *Atlantic* used by France and West Germany, and the Lockheed P-3 *Orion* of the United States Navy. The most noteworthy feature of these aircraft is perhaps the highly sophisticated use of advanced electronic technology in their navigation, submarine detection and tracking roles. The *Nimrod*, a derivative of the D.H. *Comet* airliner, is the most recent air-sea warfare (ASW) aircraft to be placed in production (1969). The *Atlantic* is a 1965 aircraft, the *Orion* is of 1962-66 vintage or even earlier, and the Canadair *Argus* is a 1957 development.

Military transport aircraft have diverged from their civilian counterparts primarily because of the need for flexibility in accommodating the wide variety of military loads to be carried and especially because of the size and weight ranges of the individual items in such loads. The largest of such transports is the Lockheed C-5A *Galaxy*, now undergoing flight tests, which can weigh 769 000 lbs. when fully loaded, carries 265 000 lbs. of cargo and has a design cruising speed of 550 m.p.h.

Of the several specialized types of military aircraft the helicopter is outstanding because of the many important roles it can undertake and its overall effectiveness therein. These include search and rescue in many environments, including the battlefield; medium transport for troops or supplies; light observation and reconnaissance; close tactical support, when suitably armed; and submarine search and detection in an air-sea warfare role. The helicopter has the highest efficiency in hovering of any vertical take-off and landing aircraft. However, it is expensive to operate because of its mechanical complexity and vibration characteristics which

*Since this was written, the USAF has initiated a competition for the development of a prototype strategic bomber, designated the B-1. Three companies—Boeing, General Dynamics and North American Rockwell—competed. A contract for seven prototypes has been awarded by the Department of National Defense to the North American Rockwell Company.

aggravate the maintenance problem. It is inherently limited in its speed of flight and is therefore inefficient as a transport vehicle (measured in ton-miles per hour). Helicopter speeds are typically of the order of 150 m.p.h., although experimental types have flown at 250 m.p.h. Gross weight of the largest of current types is about 38 000 lbs. Other types of specialized aircraft employed by the military include trainers, utility transports, intrusion and counter-insurgency aircraft, and those employed in observation and early warning.

The current civil aircraft scene is dominated by the commercial jet transports. Short-range types, weighing about 100 000 to 115 000 lbs., can carry 100 to 120 passengers over distances up to 1 500 miles with maximum speeds of around 550 m.p.h. The long-range jets are in the 330 000 to 350 000 lb. gross weight class with accommodation for 175 to 260 passengers and maximum ranges about 7 500 miles at speeds in the 600 m.p.h. region. Two gas turbines of 12 000 to 14 500 lb. thrust power the short-range types and four engines of 18 000 to 21 800 lb. thrust are used in the long-range types.

Like their military counterparts, these aircraft are equipped with a very wide range of accessories and avionics to cope with the navigation, communication and flight control functions. The picture is somewhat fluid as new equipments such as inertial navigators are introduced and all-weather landing systems appear as coming realities. Problems related to standardization, performance and reliability, and as with military aviation, the need for complete systems integration contribute to the changes which are expected to continue in this technology.

The growth in popularity of air travel is due, in part, to the lower cost and better service provided by these jet aircraft and their immediate predecessors. This growth in the number of passengers carried by the world's airlines has been tripling every 10 years and reached nearly 300 million in 1968. Despite the massive efforts in design, development and production required to get a new aircraft into service with the airlines, the aircraft industry has been able to keep pace with this rising demand. This has not been done without difficulties, one of the major difficulties being financial. On the other hand, however, practically all other aspects of the total air transportation system have failed to keep up with this pace of

progress. In a number of the critical, densely populated areas, the capabilities of airports to handle not only the aircraft themselves but the passengers using them are over-saturated. In many cases this situation extends beyond the airports, to the highway system intended to serve them. The ground transportation system for airline passengers leaves much to be desired in most cases. The airways themselves have become congested and the volume of flight traffic has led, in places, to saturation of the air traffic control systems and consequent heavy demands on the human element, especially under adverse weather conditions. This situation becomes most acute, of course, in the airport approach and departure zones where air traffic is concentrated. Busy airports are subject to almost continuous operations, with traffic arriving and departing at all hours with the exception perhaps of the earliest hours of the day. The noise generated by modern jet transports both in the approach and departure phases of flight has become a public nuisance to those living within even a generous radial distance from the airport.

Adding to this picture, and perhaps not generally appreciated, has been the phenomenal growth of general aviation, particularly on the North American Continent. This includes corporate business as well as private flying. During the last 10 years the world's aircraft manufacturers have delivered nearly 109 000 aircraft in this category (14 173 in 1968). The business aircraft sector is more and more typified by jet-powered types designed exclusively for it. As might be expected, these are high performance, high altitude aircraft fully equipped to fly in all-weather conditions.

Flight safety in these times of increasing air traffic becomes of equally increasing importance. While the airlines have established a very low rate of accidents (about 0.5 fatalities per 100 000 000 passenger-miles flown), unless this *rate* can be bettered there will be an increasing number of fatalities as the number of passenger-miles flown increases year by year. Apart from this there is even less reason to be complacent about the accident rate for general aviation. The search for engineering perfection is never-ending in aviation but air safety is not solely a question of technical perfection. It depends essentially on the man-machine interface, commencing with the design process, continuing through the manufacture and inspec-

tion stages, and culminating in flight operations where it is of major importance. For in this last phase, not only the pilot but other crew members, air traffic controllers, meteorological forecasters, aircraft maintenance mechanics and a varied host of other people all have, to a greater or lesser degree, an influence on flight safety. The greatly increased performance of the modern jet aircraft over its predecessors of yesteryear has magnified the problem.

The changing face of aviation reveals the future in the shape of the supersonic airliner, the massive "jumbo" aircraft and the vertical or short take-off and landing (v/stol) commuter, city centre to city centre. These aircraft will answer some of our present demands on the air transportation system but they bring new problems of wider range and greater magnitude to challenge our capabilities. There is much scope for research and development. The steady increase in thrust and improved fuel economy of the jet engine is proof that research and development can still yield big returns in the power-plant field. The scope for new materials in aircraft structures and new fabrication techniques is unlimited and the picture here again is full of change and promise. The graceful shapes of modern aircraft and the intricacies of the slots and flaps appended to their wings and visible during take-off and landing might suggest that we have mastered the problems of air flow around aircraft for most conditions of flight, but this is far from the truth. The vortex generators still to be seen on several modern types of aircraft, and current development work by the National Aeronautics and Space Administration on the "supercritical" wing, give the lie to that. For years, aerodynamicists have known that control of the boundary layer—that very thin layer of air which is in contact with the surface of wings and bodies—will confer many important advantages. But how to accomplish this efficiently has baffled engineers for decades. It is evident then that opportunity still beckons for further advances in aerodynamics.

Chapter IV

Aviation in Canada, 1969

A review of the current status of aviation in Canada needs to examine the structure and performance of the manufacturing industry down to the individual company level. It is also necessary to study the situation of civil and military aircraft operations, including the repair and overhaul activities which support them.

Unfortunately, it has not been possible to obtain a quick and accurate statistical description of those components of the manufacturing section of the industry which are germane to this report. For instance, it is difficult to account for all production which should be included under avionics. The nearest relevant and readily available statistics refer to the *aerospace* industry.* This report will make use of aerospace statistics since the industry is predominantly aeronautical in character.

The aerospace industry has recently become the third largest Canadian exporter of manufactured goods. The progress of the industry since 1963 has been as follows.

Fiscal Year	Domestic Sales	Export Sales	Total Sales
	in millions of dollars (Canadian)		
1963	316	234	550
1964	304	284	588
1965	290	251	541
1966	294	300	594
1967	258	402	660
1968	189	561	750
% Growth			
1968 over 1963 — 40	140	36	

Source: Air Industries Association of Canada.

The industry has enjoyed an almost constant growth over these years. Yet there has been a steady decline in domestic sales compensated, fortunately, by a rise in export sales. In 1967 and 1968 *export* business was 61 and 75 per cent of the total, respectively, and has apparently risen to become the highest percentage for any aerospace industry in the world. This is especially significant in a highly competitive business where superior performance, in quality and price, is the major sales criterion. This orientation towards export sales represents a revolutionary change in the industry from its historic pattern, brought about largely by the changed climate as regards domestic demand—in defence and the airlines—for Canadian-designed aircraft. This new climate has forced the industry to export for survival and has led to a significant transformation in business atti-

tudes. It must not be forgotten, however, that this capability to meet the needs of an export market has only been possible because of the encouragement and support derived from the Department of National Defence either directly, or through contracts for aircraft or equipment to satisfy our own defence requirements. It should also be emphasized that in most cases this export market has been a military one.† For example, of the approximately 1 650 de Havilland *Beaver* aircraft produced, over 1 200 were exported to meet light military transport requirements. The military nature of this export market is largely a characteristic also in the case of accessories and equipment, including avionics, and to a lesser extent in the case of aero-engines.

Total employment in the industry at present amounts to about 48 000—of whom some 12 per cent are scientific and technical personnel. This labour force is, in general, highly skilled and the industry is labour intensive, with a ratio of wages and salaries to value added of about 67 per cent, compared with 40 per cent for mining and even less for agriculture.‡ About 25 000 people, or over half of the total labour force, are employed in the five big companies—three airframe manufacturers and two aero-engine companies—which might be designated as the first tier manufacturers.

The manufacturers of accessories, equipment and avionics for aircraft and ground support total 23 companies, which may be considered as the second tier of aerospace firms. In addition, there are 11 other companies which do repair and overhaul as a major commercial enterprise and another 86 firms which represent sales agencies having little or no manufacturing, repair or overhaul activities in this country or which are satellite business enterprises and suppliers. This

*The term "aerospace" originated in the United States and in the case of industry is applied to those companies which design, develop or produce equipment either for aeronautical or space applications. In Canada, the products or services of some companies are related to such "space" activities as upper atmosphere sounding rocketry or the manufacture of earth satellite components. At the present time however the sum total of such space activity in Canadian industry is relatively insignificant in comparison with the aeronautical work being done.

†Recent manufacture of DC-9 and DC-10 components at Douglas Aircraft of Canada Limited is an exception, so also is the subcontract work undertaken in other manufacturing companies for such aircraft as the Lockheed 1011.

‡National Accounts: Income — Expenditure — 1967.

brings the present number of aerospace industrial firms to 126.

There are three classes of production which underlie aviation manufacturing in Canada:

1. *The design and production of proprietary products in response to either general or specific market requirements.* The proprietary production situation gives the manufacturer complete independence to compete in the world market with his own products. His success will be related to his skill in managing the productive resources at his disposal (including R & D) and his marketing ability.

2. *The production, under licence, of either the parent company's, or some other company's proprietary products for a limited market.*

Licensed production represents a lower risk situation for the manufacturer. It also represents a limited market, and a limited opportunity for the application of R & D efforts towards product improvement.

3. *The production under special arrangements between two companies, of the first firm's proprietary products on a subcontract basis by the second firm for the first.* Subcontract production is the least desirable from the point of view of the integrated manufacturer—that is, one whose operations are structured on the basis of the full and complex range of R & D, production engineering, manufacturing and marketing activities. Under this third class of production, the manufacturer has relatively little scope for R & D or for any elaborate “in-house” technical services.

The five main airframe and aero-engine companies have generally been regarded as the prime contractors in relation to the rest of the industry. Some of these manufacturers have themselves, in the last few years, taken on the role of subcontractor to larger foreign firms to the extent that this has become a very important part of their total business. This situation has, in turn, resulted in both opportunities and problems for some of the second tier manufacturers. It should be remembered that the five first tier companies are owned by U.S. and by British parent companies. However, the more widespread second tier companies are also subject to heavy U.S. and U.K. investment in the Canadian aerospace industry, with over 80 per cent of these enterprises being foreign-owned and controlled.

The recent export sales of the industry as a whole were divided between proprietary products, products built under foreign li-

cence, and production for foreign markets under subcontract arrangements. The largest recent increase was in subcontract production. Thus, it follows that the exigencies of competition with foreign manufacturers—who can also be the principals of the Canadian firms—have brought about changes and adjustments in the business practices of the aerospace industry. The customers for Canadian-made products now have available, for bargaining purposes, an unusual amount of what might be termed “proprietary” cost information. The negotiations which have resulted from such “inside” knowledge on the part of the customer have had a depressing effect on profits from manufacturing activities over the recent short term.

While the long-term view is possibly clouded by uncertainty for some firms, it appears to offer a more promising future for others, based on their present relative strengths with regard to capital resources, skilled management and manpower and, most important, innovative engineering ability. Some excellent progress has been made in recent years by a number of firms which are marketing products of their own design. For those firms which do not now have a proprietary product capability, there are two strategies for achieving a degree of independence from prime contractor domination. One way is to arrange for exclusive North American or world production rights for suitable products designed by the parent company. The second strategy, which usually follows the first, is to take on the continuing product design responsibility along with the exclusive production rights. This latter course has the advantage of fostering innovation through continued application of R & D efforts; this is a key business concept for future Canadian aeronautical industry planning.

Airframes

The airframe manufacturing industry consists of three large companies—Canadair, de Havilland, and Douglas, with a total in-house employment of about 18 000. There are also a small number of intermediate-size firms, which are engaged mainly in repair and overhaul, and a larger number of small firms which operate mainly on a subcontract basis as suppliers to the larger firms. This last group represents a valuable avenue for the

diffusion of aeronautical technology throughout a broad support base wherein skills and capabilities can be utilized to help sustain the major companies and to exploit new business opportunities and new export market potentials.

Canadair Limited, in Montreal, is one of the three giants of the airframe business. This company has built many types of aircraft, predominantly under licence, but also from its own designs. At the present time, it has substantial contracts related to U.S. military aircraft—for example, for major components for the Lockheed C-5A *Galaxy* transport, for wing and tail components for the General Dynamics F-111 fighter, and for rear fuselage sections for the Northrop F-5. The F-5 fighter, designed by Northrop, and modified for the Canadian Armed Forces by Canadair, is in production and substantial numbers are being sold in the export market. The CL-41, two-seater trainer/tactical support aircraft, designed by Canadair in the first instance for the Canadian Forces, is also in production and has been exported to foreign countries.

The de Havilland Aircraft of Canada Ltd., at Toronto, has concentrated almost exclusively in recent years on the design and production of short take-off and landing (STOL) aircraft, ranging in size from the *Beaver*, with a gross weight of approximately 5 000 lbs. and a seating capacity of 7, to the *Buffalo*, with a gross weight of 40 000 lbs. and a seating capacity of 45.

The Douglas Aircraft Company of Canada is the newest of the airframe "Big Three" and is also located at Toronto. At the present time, Douglas is engaged in the large-scale manufacture of DC-9 wing and tail components and has just begun production of wing boxes for the DC-10 aircraft.

Aircraft Power Plants

The two main aircraft engine companies are United Aircraft of Canada, Limited, at Longueuil, Quebec, and Orenda Limited at Malton, Ontario. In addition, Rolls Royce Limited, at Montreal, is an aero-engine company of intermediate size. In 1968, these Canadian aero-engine companies had total assets of \$150 million, with sales running at about \$200 million and employment at 7 500 people. To support these companies, there are over a hundred companies which develop and (or) manufacture components, parts and

accessories, and supply specialized raw material as subcontractors to the prime manufacturers in Canada. Reflecting the same situation as in the airframe industry, this broadly based supporting industry has exploited the subcontracting opportunities to supply materiel to prime U.S. manufacturers as well as to manufacturers in Canada.

The growth and expansion in capabilities of the aero-engine industry in the post-World War II period resulted from the federal government's policy to establish a development and production base in order to minimize our dependence on foreign sources for the supply and support of our defence needs. Orenda, the first company to acquire these capabilities, owes its origin to the government's desire to utilize the gas turbine technology it had acquired, beginning in 1941, through the National Research Council and subsequently in the Crown Corporation, Turbo Research Limited. The *Orenda* engine, which powered the CF-100 and later models of the F-86 aircraft, was the first engine developed by Orenda Ltd. for production and use in front-line military aircraft. Work on the *Iroquois* engine, intended as the power plant for the CF-105 *Arrow* fighter, was terminated when the *Arrow* was cancelled in 1959. Since that time, the company has engaged in the manufacture of aircraft gas turbine engines under licence, has supplied parts to U.S. manufacturers, and has become active in the development and manufacture of industrial gas turbine engines.

Rolls Royce constructed a manufacturing, overhaul and assembly plant in 1952. The motivation behind this was a contract with Rolls Royce in Britain for over 900 R.R. *Nene* turbo-jet engines required for T-33 trainers for the Royal Canadian Air Force. Prior to that time, the activities of Rolls Royce Canada were mainly in support of the *Merlin* engine used by the Royal Canadian Air Force and Trans-Canada Air Lines. Today, the company services and overhauls aero, marine and industrial engines manufactured by the parent company for customers throughout North America; it also manufactures engine parts.

United Aircraft of Canada can trace its origin back to 1928. Before 1963, it was known as Canadian Pratt and Whitney (P and W) and had a history of service and overhaul support for P and W aircraft engines operating in Canada. In 1951, the federal government requested that the com-

pany provide a facility for the manufacture of P and W R1340 engines for the *Harvard* trainer. After this program was an order for the production of Wright R1820 engines for the Canadian-built CS2F *Tracker* aircraft. This experience enabled the company to secure a licence to manufacture spare parts for all P and W piston engines and to distribute them throughout the world. In 1957, the company recruited an R & D group which became the nucleus of the organization that later developed the PT-6 series of small gas turbine engines. The company also provides sales, service and overhaul support for other products of the parent company, United Aircraft Corporation, which are not made in Canada.

Repair and Overhaul

The maintenance, repair and overhaul (M, R and O), and the design of modifications for aircraft, engines and aircraft products have become a most significant element of the aviation industry in Canada. It is estimated that about 200 companies engage in this role and do some \$100 million of business each year, for the existing civil and military aircraft fleets.

It is difficult to judge the extent of the pure repair and overhaul activities of these support companies because all the shops engage in a mixture of maintenance, repair and overhaul depending on the demands of the aircraft operators. Further, the Department of National Defence (DND) and many larger operators perform their own maintenance, but tend to contract for R and O work. Air Canada and CP-Air possess extensive skills and often perform R and O for other carriers as well as for their own fleets.

The Department of Transport (DOT) has approved about 60 companies to do R and O, and another 170 companies are approved to do maintenance plus limited R and O. Many of the prime DOT-approved R and O companies also hold DND approval for military aircraft, but because the military contracts have been on the decline, there has been a marked change in the larger R and O companies. These changes have caused the well-equipped jet-age shops to diversify and to seek more civil aircraft business or foreign military contracts.

The M, R and O shops, large and small, have difficulty in establishing steady pro-

duction because of the seasonal aspect of many flying operations, and the dispersion of the operators which precludes an adequate flow of work in most areas where the R and O shops are located. The small shops primarily serve the small single- and twin-engined aircraft while the large shops look after the larger and more complex aircraft. In both categories there is real competition from U.S. R and O companies because the U.S. shops are very often located closer to the operator than the competent Canadian shop, and prices are often more attractive because of the larger U.S. production runs. The result of all these considerations has caused the R and O business in Canada to be uncertain and the business of many shops fluctuates annually. However, there are several companies which have succeeded in augmenting their R and O activities by undertaking design and development of aircraft modifications for the specialist operators, or by acquiring manufacturing subcontracts to the aircraft manufacturing industry; a few examples will be discussed.

Northwest Industries, at Edmonton, besides repair and overhaul, has acquired a substantial contract for jumbo-jet components, plus contracts for components for two general aviation aircraft. The company has assembled a small design and development office which has developed a light-weight seat which is soon to be marketed. It also produces jet aircraft interiors and undertakes the installation of avionic equipment. Its subsidiary, CAE Aircraft Ltd., of Winnipeg, commenced operations in 1969 on a significant scale and is programmed to perform the R and O on Air Canada *Viscount* aircraft as long as they are in service, and has a large contract with the United States Air Force for *Sabreliner* overhauls.

Field Aviation Ltd. serves five areas of Canada and at its main facility, at Oshawa, it has established a design and development capability which has been highly successful in the production of water bomber systems which are revolutionizing the forest fire bombing operations.

Bristol Aerospace (1968) Ltd., at Winnipeg, has contracts for jumbo-jet parts and is now the world's sole producer of JATO engines.

Standard Aero Engine Ltd., of Winnipeg, is one of the largest companies in engine repair and overhaul in North America, with in-depth skills for both reciprocating and turbine engines.

Aviation Electric Limited, of Montreal, has pioneered in the R and O of aircraft accessories since 1931. The continued growth of the technical requirements and of product diversification to support the Canadian aircraft industry resulted, in 1952, in the need to establish engineering and component manufacturing facilities for instrumentation and gas turbine fuel systems production. The existence of these facilities, in turn, served as a basis for the expansion of the equipment and services of the R and O operation to the extent that this company is recognized today as Canada's largest aircraft accessory and instrument R and O establishment.

The activities of the smaller companies are quite modest, but nevertheless they develop float installations, heater installations, boat carriers, helicopter external load adapters, agricultural spray gear, magnetometer installations and many more special equipments.

Because of the introduction of the small turbine engine, pressurized fuselages, and advanced navigation-communication equipment into the general aviation aircraft field, the small repair and overhaul shops are facing the problem of expanding their facilities. As this trend develops, under the pressures generated by the growing numbers of civil aircraft, these small R and O shops will be obliged to seek business sources other than the aircraft operators to remain viable, and this could lead to a closer relationship with both the manufacturers and the large air carriers.

However, it is evident that in spite of the size of the repair and overhaul business in Canada the uncertainties which these companies face will continue until the civil fleet has expanded by a significant amount and the problems of base dispersion and isolated locations are overcome.

Accessories, Equipment and Avionics

The companies included in this category are the principal Canadian manufacturers of proprietary equipment and accessories for the aviation industry. Each of them employs more than 100 people, manufactures frequently under licence from a foreign parent or other company, but has sufficient research and development facilities to pursue specialized development work and technological improvement of its existing products. Sales by these companies are most usually depend-

ent on negotiation with the first tier prime contractors. A list of these manufacturers and some brief notes about their products are given in Appendix 5. The activities of many of these companies are discussed in more detail in what follows.

Abex Industries of Canada, at Montreal, has a long history of successful development and sales in the hydraulic accessories field for such components as hydraulic actuators and landing gear assemblies. The company and its predecessor, Jarry Hydraulics, have been extremely successful in both Canadian and U.S. markets and their components have been used in aircraft such as the CL-41, CF-5A, CL-84, CL-215, de Havilland *Buffalo* and *Caribou*, the F-5, F-111, XC-142, and the UH-2 helicopter.

The Dowty Equipment Company of Ajax, Ontario, competes in the same market as Abex Industries and produces landing gear components and control surface actuators. Its markets are principally in the United States and Canada.

Aviation Electric, also at Montreal, has 17 years experience in manufacturing aircraft instruments and accessories such as fuel controls, rate of climb indicators, and directional gyros. Most of these have been built for the Canadian market under licence. One of the company's strongest product lines—jet engine fuel controls—now accounts for a high percentage of its total manufacturing output. Another successful product has been the land navigation system which was developed originally for the Canadian Army and is now enjoying considerable export sales.

The Electronics Division of CAE Industries Limited, at Montreal, has developed and produced magnetic anomaly detection (MAD) equipment for air-sea warfare (ASW) use. This equipment is in service with the Canadian Forces, the Royal Air Force, the U.S. Navy, the Royal Netherlands Navy, the Royal Australian Navy and Air Force, and with several geophysical exploration companies. This all-Canadian company has also pioneered in the development and manufacture of flight simulators for Canadian and world markets. A number of F-104-type simulators are in service with the Canadian Armed Forces and NATO countries. More recently, orders have been received from 10 international airlines for digital flight simulators. The aircraft types to be simulated include the Douglas DC-8 and DC-9, the Boeing 747 and the Lockheed L-1011.

The Canadian Marconi Company, of Montreal, has become famous both nationally and internationally for its development and production of a series of Doppler radar equipments. More than 3 500 sets of this series are flying in a variety of military and civil aircraft throughout the world. The company has also developed airborne navigation computers and has sold them as accessory items to their radar.

Computing Devices of Canada, based at Ottawa, became well-known in the aircraft navigation field with the development of its own position and homing indicator (PHI) which has been sold for use in many of the world's air forces. This company has also developed and produced a sophisticated navigation system for use in transport and ASW aircraft.

Ferranti-Packard Limited, of Toronto, has invented, developed and manufactured what is currently the most advanced airport information display system and is supplying it to airports in Canada and around the world. The success of this system has led to the widespread application of it beyond the airport environment. Large installations are already in operation in the Montreal and Canadian Stock Exchanges and at the Chicago Board of Trade.

Philips Electronic Industries, at Toronto, has acquired a worldwide reputation for its communications control and radio beacon systems for use in air traffic control. The Philips dual radio beacon was specially designed in Canada for the Canadian airways and for International Civil Aviation Organization requirements, and for land-based navigational aid at remote unattended stations. A special radio beacon monitoring system was designed to operate with this beacon.

Garrett Manufacturing Limited, of Rexdale, Ontario, has designed and developed in Canada a series of airborne static inverters and sold them to civil and military customers in the United States and Canada. The company is the sole source for its parent company of aircraft air-conditioning components, most of which are supplied to export markets.

Litton Systems (Canada) Limited, also of Rexdale, is a major Canadian exporter of avionic equipment. As one of the world's leading producers of inertial navigation systems, it has supplied a variety of them for use in different military aircraft. The parent company has now selected it to be the sole

source of inertial navigation systems for commercial and civil aviation. The company has also been a major producer of weapons release computer sets. It has designed and developed mobile automatic test sets (MATS) for the ground testing of inertial navigation systems, and these have been sold in both the domestic and export markets.

Leigh Instruments, of Carleton Place, Ontario, is a relatively new but rapidly growing Canadian company. It has designed and manufactured a crash position indicator (CPI), which was first developed by the National Aeronautical Establishment, and which is now used by the Canadian Forces and the U.S. Air Force. A light-weight version of the CPI has been developed for sale in the general aviation market. The company is now a major supplier of flight data recording equipment for military and commercial aircraft.

The manufacture of ground-based avionics is the latest contribution to visual communications of the RCA Victor Company of Montreal. The RCA-DIVCON display system is now installed in airports, but has wide civil and military applications where there is a need for the continuous display of updated information.

Another company whose main lines of production serve industries other than aviation is Uniroyal Limited. Its Aircraft Products Division, located at Montreal, has developed safety "rubber" fuel cells. Almost all Canadian-developed aircraft are equipped with them. The cells are also being used in many U.S.-developed aircraft such as the F-94, B-24, SB2C-1, T-33, T-34, T-38, X-142 and the UH-12E helicopter.

Aircraft Operations—Military

The air operations of the Canadian Forces can be segregated into eight roles of which, from the point of view of cost, six are major and two are minor. In decreasing order of costs (1968-69) the major roles are maritime warfare (air), airlift, air strike/reconnaissance, flying training, air defence and tactical air. The minor roles are air repair and maintenance, and air search and rescue.

It is not possible, owing to the classified nature of the information, to provide precise figures regarding operational hours flown per month, or per aircraft. However, Appendix 6 gives information on the magnitude of the air operations of the Department of National Defence for personnel and costs,

broken down into the eight operational elements of the Forces. Appendix 7 contains information on the present inventory of DND aircraft, but here again precise figures for key operational aircraft cannot be released for security reasons. While the magnitude of the air operations has decreased somewhat in recent years, the Armed Forces do conduct very large operations by any standard, employing over 1 200 aircraft of 28 different types. Over 33 000 people are employed, and the cost is in excess of \$442 million.

The maritime warfare operations are based primarily on *Argus* aircraft, operated from land bases, and the *Tracker* aircraft and the CHSS-2 helicopter, operated from naval ships. The airlift operations of Air Transport Command involve a variety of aircraft including the long-range *Yukon* and C-130, and the smaller *Cosmopolitan*, *Dakota*, *Caribou*, *Falcon*, and *Otter*. The air strike/reconnaissance role is performed with the CF-104 *Starfighter* while the air defence operations are conducted by six squadrons equipped with the CF-101B *Voodoo*. The air operations of Training Command also require a variety of aircraft with substantial numbers of *Tutors*, T-33s, *Chipmunks*, *Expediteurs*, and *Dakotas*. The formation of Mobile Command in recent years has seen considerably increased emphasis on the tactical air role. At present, the *Buffalo* and a variety of helicopters are used, while the CF-5 is being produced to expand these operations further. Search and rescue operations are based mainly on the *Dakota* and *Albatross* together with some helicopters.

Capital expenditures on aircraft acquisition vary considerably from year to year but recently have been between \$50 and \$100 million. They amounted to \$80 million in 1968-69. Notwithstanding these substantial expenditures, it can be seen that the Armed Forces possess a considerable number of quite old and obsolescent aircraft which will soon require replacement. The Canadian Forces themselves enjoy an excellent reputation for the quality of their training and their efficiency and skill in operations. The antecedent Royal Canadian Air Force was highly technically oriented and was knowledgeable and skilled in the use of the most up-to-date equipment. It is to be expected that this tradition, despite shrinkages in personnel numbers, will continue. Hence, it is likely that when the question of equipment replace-

ment arises, the Canadian Forces will be looking for the most modern types of aircraft and avionics, typifying the very latest in technology. This will provide an opportunity for a trade-off between reduced personnel numbers and equipment sophistication whereby the overall efficiency in operational roles can be maintained or even increased.

Aircraft Operations— Civil and Commercial

Civil aviation is controlled and regulated under the Aeronautics Act which defines the responsibilities of the Minister of Transport and the Air Transport Committee with regard to the safety, development and reliability of aviation.

The Department of Transport undertakes the operational surveillance of all civil aviation and provides services in support of this role in the form of airports, airways, air traffic control facilities, and meteorological and telecommunication aids. Some of these services are also used by foreign air carriers as well as Canadian-registered aircraft and military aircraft. The Air Transport Committee grants licences for the operation of commercial air services and in conjunction with this role, undertakes the analysis of the needs and benefits of these services. Licences for foreign air carriers are usually negotiated on a bilateral basis with foreign states, subject to certain clauses of the Chicago Convention of the International Civil Aviation Organization.

The Civil Aircraft Register in Canada has increased from 260 aircraft at the end of World War II to 10 800 in 1969 and is now the second largest register in the world. Approximately 70 per cent of the aircraft registered at the present time are in the private category. The rest are primarily commercial and state-owned aircraft.* The commercial aircraft are operated by 450 licensed carriers. There are also another 390 foreign operators licensed by the Air Transport Committee to enter Canada. The number of licensed pilots exceeds 35 000. The aircraft population consists of approximately 9 000 single-engine types, 1 200 twin-engine types, 175 multi-engine types, and 500 helicopters. The aircraft utilization statistics for 1967 show that a total of about 2.25 million hours were flown by just over 9 000 aircraft.

*Approximately 200 are state owned.

Of this total, 2 per cent of the aircraft were flown by commercial scheduled carriers for roughly 20 per cent of the hours logged. Non-scheduled carriers flew 50 per cent of the hours, and private and state aircraft the remaining 30 per cent. The Department of Transport has estimated that in 1967 the owners of all but the scheduled carrier aircraft spent \$95 million on operations. The scheduled carriers had total revenues in 1968 of almost \$500 million. Of this, Air Canada's share was \$387.6 million and the share of CP-Air was \$106.7 million. Between them, these two airlines flew over 7.3 billion passenger-miles in 1968 which, when added to all other civil flying, placed Canada in second position in the world in the use of aircraft.

Air Canada's business has grown at a steady rate of about 16 per cent per annum over the last 30 years. In fact, in 1968, Air Canada flew a greater number of passenger-miles than any airline in the western world outside of the United States, and its operations were exceeded by those of only six of the U.S. airlines. Its success has been due to many factors. To begin with, it has been free of political interference and has been able to select the best equipment available, regardless of source, in order to remain fully competitive with other airlines. It has also been technically progressive—one of the small group of top airlines which has played a major role in assisting the aircraft manufacturers in the development of today's air transports. The exchange of information on current problems within this group and with the manufacturers has advanced the safety and reliability of air transportation.

Canadian Pacific Air Lines (CP-Air), though smaller in operations and with less than one third the passenger-miles flown by Air Canada, has won a reputation for efficiency and good service, outstanding utilization of its equipment in terms of hours per annum per aircraft, shrewd attention to overall route structure, and better-than-average profitability.

The question of profitability is perhaps the major cloud in the overall picture. Competition is so keen in air transportation that the profit, as a percentage of capital investment, is both small and precarious. As an example, the Canadian scheduled carriers had a net profit after taxes of \$15.7 million in 1966, \$11.1 million in 1967, and \$11.9 million in 1968.* With total assets in 1966 of \$479

million, the profit was only 3.28 per cent of assets. This profitability picture is so marginal that if a hub airport, such as Toronto, is closed by fog for a few days more than usual during a peak traffic period, then an airline's profit may be turned into a loss for that year. A similar effect can result if an airline encounters trouble with new equipment and runs into maintenance or reliability problems. From a purely business point of view then, a large part of this industry appears to offer a poor return on capital.

Private flying in Canada in 1963 accounted for about 512 000 aircraft hours flown, representing about 35 per cent of the total hours flown by private and commercial aircraft. Between 1964 and 1968 private flying increased sharply, exceeding 800 000 hours in the latter year. However, the rate of growth of commercial aviation outstripped it so that in terms of hours per annum, private flying declined to 30 per cent of the total for that year. This still represents a very healthy segment of the flying operations in Canada and reflects the growing activities of personally owned and business aircraft and the recreational opportunities offered by the member clubs of the Royal Canadian Flying Clubs Association.

The air cargo growth achieved by commercial operators is shown by the fact that the volume of air freight and air express increased more than fivefold in the eight years from 1960 to 1968—from only 24 000 tons in the former year to 125 000 tons in the latter. A further illustration of this growth is given in the 1968 ICAO Annual Report which lists Canada in sixth position among the member states with an increase of 35 per cent over 1967 cargo operations.

The Canadian air navigation system includes over 37 000 nautical miles of low-altitude airways, 10 000 nautical miles of low-altitude air routes, and 31 000 nautical miles of high-level airways. There are 1 700 airports, including landing strips, of which 175 are used regularly by commercial carriers. Air traffic control facilities are to be found at 60 airports, and these facilities are supplemented by 200 beacons strategically located within the navigation system. The traffic control centre at Gander, Newfoundland, for example, handles all the North Atlantic air traffic west of longitude 35° W both to

*Preliminary Annual Report on Civil Aviation. Dominion Bureau of Statistics.

and from Eastern Canada and the North-eastern United States and is equipped with both primary and secondary radar like those of the eight international airports within Canada.

The Department of Transport has, over the years, provided the essential ground facilities to serve the needs of all segments of the flying community. The phenomenal growth in popularity of all forms of flying has severely taxed these facilities. The airline passenger, exposed to the air-ground interface, is aware how quickly first-class airport terminals, built a few years ago, have become congested. The construction costs for these facilities are very high indeed and more than \$620 million has been spent on them in Canada since World War II. While the Department—with an annual budget of \$146 million—copes with the problem of the growing numbers of air passengers, the expanding air traffic places its burden on the air traffic control and air navigation systems. Fortunately the spectacular advances and growth in the field of electronics have permitted revolutionary changes in the equipment that can be specified for such systems. Here again the Department has the opportunity to utilize this new technology to modernize these systems to meet the demands required of them. This will look after the main airway system but the growing volume of private flying calls for special, low-altitude capabilities. The picture here is one of a demand for navigation facilities which are either non-existent or inadequate to meet the present needs in certain areas of the country.

The Department of Transport has recognized the importance of flight safety management and is planning to establish a flight safety division. An integral part of flight safety is the area of pilot training, instrument flying techniques, blind landing procedures, and air carrier operations. Studies, investigations, testing and carrier surveillance are conducted on a continuing basis. In fact, the air accident rate in Canada over the past five years has varied very little in spite of the annual increase in the fleet and in the hours it operates. In 1967, the most recent year for which statistics are available, the total accident rate was slightly less than 2 per 10 000 hours flown, with a fatal accident rate slightly above 0.3 per 10 000 hours. The Canadian scheduled carrier accident rates compare favourably with those of the other ICAO member countries.

For the certification of aircraft, engines, and aircraft products, the Department of Transport has always relied on the airworthiness requirements of the United States and the United Kingdom but, currently, the Department is studying the feasibility of establishing Canadian airworthiness requirements. The study is particularly concerned with the special requirements of Canadian operating conditions, the need for the maximum adherence to internationally agreed standards, and the need for a comprehensive research and development program to investigate selected special requirements.

Before closing this chapter, it seems appropriate to discuss some of the current activities of the Canadian Transport Commission in aviation. The overall responsibilities of the Commission embrace a national transportation policy and system for Canada. This system must be efficient, economic and adequate and must make the best use of all available modes of transportation. The Commission has within its structure a Research Division which, in turn, has three branches: one to study policy development, one to study economics and systems analysis, and a third to study the scientific and technical aspects of transportation. While the work of all of these branches has a bearing on aviation in Canada, the work of the Science and Technology Branch is perhaps most relevant to this report. Its work is mainly concerned with operations research and with the “hardware” of transportation. Activities in this latter field are being organized along three separate lines. The first is a technological “look out” activity which will review new and up-coming transportation technologies on a worldwide basis and which will assess them from the Canadian standpoint. The second is an integrative activity which will attempt to link new forms of transportation with existing forms. The third activity will be concerned with getting new technology transferred into industry, to encourage its use, and to see that it contributes to improvements. The Science and Technology Branch is particularly interested at the present time in the future of STOL aircraft, while the Commission as a whole is studying the transportation problems of the Montreal-Toronto corridor intensively. Short take-off and landing aircraft may eventually play a large part in the solution of these problems and as a means of opening up the remoter parts of Canada.

One final comment. Canadian civil aviation operations have a particular status in the world because Canada is the second most active aviation country. In this country, we rely upon aircraft for transportation, for exploration and the exploitation of natural resources, and for the maintenance of national sovereignty. But while aviation operations in this country have progressed technically and contributed significantly to the international scene, there is still an element of pioneering in Canadian aviation which should be nurtured. Canada's need for expansion in civil aviation is still one of the greatest in the world.

Chapter V

Current Canadian Aeronautical Research and Development

The most recently published aggregate statistics of Canadian expenditures related to aeronautical research and development were included in a report compiled and published by the federal Department of Industry in 1967.* According to Appendices 26 and 27 of that report, the operating and capital expenditures in this country in the fiscal year 1965-66 for *aerospace* research and development (excluding avionics) were about \$57 million and, for *avionics* R & D by itself, another \$41 million—a total of about \$98 million. The breakdown of these aggregates by funding and performance on a percentage basis is as follows.

	Performance Percent (Rounded)	Funding Percent (Rounded)
<i>Aerospace (excluding Avionics):</i>		
Canadian Government	13.5	43.5
Foreign Government		16.5
Industry	78.5	32.0
Universities	8.0	8.0*
<i>Avionics:</i>		
Canadian Government	8.5	50.0
Foreign Government		20.0
Industry	90.5	29.0
Universities	1.0	1.0*
<i>Total:</i>		
Canadian Government	11.5	46.0
Foreign Government		18.0
Industry	83.5	31.0
Universities	5.0	5.0*

*Includes *all* sources of funding—the universities themselves, industry, private sources and Canadian and foreign governments.

These figures clearly show the leading part played by industry in the performance of research and development associated with aeronautics in Canada. As has been mentioned already, the aerospace industry in this country has a very large aeronautical component.

Estimates of more recent expenditures on aerospace R & D in Canada have had to be made on a piecemeal basis and on the basis of incomplete information. Expenditures on aerospace R & D—excluding avionics—have shown a tendency to fluctuate quite widely from year to year, but avionics R & D work has apparently been rising steadily. On the broad assumptions that the former has not declined since 1965-66 and that the avionics component has advanced at the rate of about 10 per cent per year, the operating and capital R & D expenditures associated with aeronautics in Canada should be in the region of \$110-\$120 million for the fiscal year

1968-69. If the national aggregate operating and capital R & D expenditures for this particular year were between \$900 and \$950 million, then aeronautical research and development would account for 11 to 14 per cent of the total.

In the course of its work, the Study Committee has been more concerned with reviewing the content and management of aeronautical R & D programs and projects than with obtaining complete and precise statistics for the activities. The remainder of this chapter has therefore been devoted mainly to program and project descriptions.

Research and Development at the National Research Council

The physical and intellectual facilities for aeronautical research and development are to be found, and are “on call”, within a number of organizational subdivisions of the National Research Council’s laboratories. Radar, radio and electronic expertise, for example, is to be found in the Radio and Electrical Engineering laboratories, and it is Council policy to ensure that support for aeronautical research from this area of expertise is available as it is needed. Similarly, with regard to polymers, to fire research, or to photogrammetry and standards, the expertise and facilities of the Chemistry laboratories, the Building Research laboratories and the Physics laboratories can be made available. But the principal continuing NRC activities in aeronautics take place in the laboratories of the National Aeronautical Establishment and the Division of Mechanical Engineering.†

In these laboratories is deployed a very substantial strength in aerodynamics, propulsion, materials, structures, instruments, fuels and lubricants, and flight mechanics, as well as certain specialized capabilities related to low temperature problems, “human engineering”

*Canada. Department of Industry. Inventory of capabilities and resources of the Canadian aerospace community: Economic history and performance of the Canadian aerospace industry. Vol. 2. Ottawa, August 1967.

†The relevant scientific and technical interests of these two Divisions are organized in the following way:

National Aeronautical Establishment: Low Speed Aerodynamics; High Speed Aerodynamics; Unsteady Aerodynamics; Flight Research; and Structures and Materials.

Division of Mechanical Engineering: Gas Dynamics; Engines; Low Temperature Laboratory; Fuels and Lubricants; Engineering; Control Systems; and Analysis Laboratory.

and operational problems. In all of these areas, however, the work done within the laboratories by the scientific and technical experts is not exclusively devoted to aeronautical research and development.*

The replacement value of the existing capital plant utilized for aeronautical work in the NRC laboratories has been estimated at more than \$40 million and, generally speaking, the facilities are of a kind not available elsewhere in Canada. The capital plant was designed to be of maximum assistance to industry, often with the active co-operation of industry and at industry's request. Some details of the major elements in this capital plant have been given in Appendix 8 of this report. From this list, it may be deduced that the laboratories are not equipped to deal with all the subdisciplines of aeronautics uniformly. Aerodynamics, propulsion, flight mechanics, and structures are reasonably well provided for, while areas such as avionics, aircraft systems, materials, and aviation medicine are less well supported. To some extent, this lack of uniformity has its origins in history. For example, materials research has been, and continues to be, primarily the responsibility of the Mines Branch of the Department of Energy, Mines and Resources, and the National Research Council has tended to limit its own activities to research on materials applications of significance to aeronautics. Similarly, the field of aviation medicine has been supported primarily by the Defence Research Board and the Department of National Defence and NRC's involvement has been minimal.

During the past 25 years, the NRC laboratories have worked in support of the design, construction or operation of every significant aircraft and engine type built in Canada. The National Research Council's wind tunnels have been in particular demand by aircraft constructors and during this period of time, the output of the tunnels has supported the development of aircraft having an aggregate contract value in excess of \$2 billion. Current industrial work in the wind tunnels exceeds 2 000 operating hours per year and is paid for in part by contracts from the individual companies. Similar activities and arrangements pertain markedly to propulsion, flight mechanics and structures.

A list of selected current aeronautical laboratory projects within the National Research Council has been presented in Appendix 9 of this report. It will be observed from this list

that the current projects are almost invariably related to explicit "needs-to-know". These needs are often industrial in origin, but they also arise from the mission requirements of other government departments, from the responsibilities and objectives of national and international committees, and from the special NRC-university relationship. There are few projects which reflect a purely "in-house" requirement or conviction. Appendix 10 of this report contains a selected summary of the aeronautical R & D capabilities of the NRC laboratories.

Research and Development in Industry †

Airframe Companies

Apart from the requirement for extensive re-design of aircraft before production, Canadair Ltd. has engaged in the development of aircraft of its own design in recent years, beginning with the CL-41 jet trainer. The CL-215 amphibian water bomber, developed by Canadair, is unique in being the first aircraft ever to be designed specifically to fight forest fires. The company has also designed, developed and produced a surveillance drone for the gathering of tactical intelligence in forward battle areas. This program began as a private venture but was later adopted as a tripartite military system by Canada, the United Kingdom and West Germany. In the advanced experimental aircraft field Canadair is developing the CL-84 v/stol, tilt-wing aircraft which has flown extremely well as a test vehicle. Three operational prototypes are now under construction for evaluation by the Canadian Armed Forces.

Since World War II, the aircraft built by the de Havilland Aircraft of Canada Ltd. have mainly been of native design and development, sparked initially by the requirement for small, rugged transport aircraft for bush operations. In fact, the de Havilland stol series may be described as general utility aircraft, on wheels, floats or skis, intended for use predominantly in underdeveloped areas of the world. The *Twin Otter* and *Caribou* have gained substantial domestic and international

*For example, aerodynamicists using NRC wind tunnels have studied the effects of wind on locomotives, buildings, bridges, ships' superstructures and air pollution.

†Appendix 11 of this report contains a number of examples of Canadian products which have received financial support from the federal government and which have been successful in the marketplace.

sales with approximately 300 of each type being produced to date. The *Caribou* is now flying in some 11 countries and the *Twin Otter* has found favour in short-haul commuter air services; in fact it appears to be the leading aircraft in this rapidly expanding market in the United States. De Havilland's success has lain in its choice of size, style and design features which would not place it in direct competition with the large aircraft designers of the United States on the one hand, and the producers of the smaller aircraft for the general aviation market on the other. The company has now embarked on the design and development of the next in its series of STOL aircraft—the four-engined DHC-7—which is specifically aimed at meeting this world requirement for a commuter aircraft which can be operated from STOL-ports located in downtown areas. If this aircraft can be produced in a timely fashion it could capitalize on the success of the *Twin Otter*. It promises to have design features which should make it particularly attractive for this type of service.

Although most aircraft firms engage to some extent in development, using the talents of their engineering staff, only Canadair and de Havilland have full-time research teams. In both firms, the Defence Research Board sponsors company-inspired research programs under the Defence Industrial Research (DIR) cost-sharing program. Both firms make extensive use of the test facilities operated by the National Research Council and there is a reasonably good interchange of information between the government laboratories and the two firms. Through the medium of NRC Associate Committees and informal contacts, a reasonable exchange of information also occurs between these companies and those universities which have major aeronautical programs.

At de Havilland, the emphasis in research is in the field of high lift, stability and control, structures and materials. As might be anticipated, there is considerable attention to the design problems of wings for high lift at low air speeds, the work calling for analytical studies, wind tunnel experimentation and full-scale flight testing. In the stability and control work extensive analytical studies are supplemented with work in simulators—both at the company and at the National Aeronautical Establishment—and full-scale flight testing in company aircraft. The structural work is somewhat more prosaic, although some very interesting original work has been

performed on the dynamics of undercarriages designed for rough field operations. In materials, some studies have been conducted with components formed from plastics reinforced with honeycomb materials and composites.

The work at Canadair follows the same general pattern as that at de Havilland, with considerable attention being paid to the aerodynamics of high lift and propeller (or rotor) performance at low air speeds. Canadair has developed advanced techniques in the structural field, such as the high-speed computational analysis of redundant structures.

The Douglas Aircraft Company of Canada Ltd. is not yet active in research and development to the extent required to support the design of new aircraft, and it has not, as yet, established any research and development facilities. Mainly, the equipment available is that required to support the manufacturing organization, inspection and quality control services and the like. This is not to suggest that there is any lack of vision. On the contrary, the company has demonstrated much original thinking and novelty in its approach to its manufacturing operations, and the atmosphere within the company would appear to be highly conducive to research and development should the decision be taken to engage in *ab initio* design.

While discussing aircraft development, mention must be made of the gyroplane which has been developed by one of the smaller companies—Avian Aircraft Ltd., of Georgetown, Ontario. This aircraft, which received its Department of Transport certification in late 1968, uses a free-wheeling rotor for support, which can be spun up to permit vertical "jump" take-offs; it is also capable of steep landing approaches. This project is now at the production stage following a nine-year development period during which six prototypes were built.

Bristol Aerospace Ltd., at Winnipeg, has achieved an excellent reputation for the design and production of specialized items such as the hot components for air ducts and engine nacelles, airframes and motors for rockets, and seaplane floats.

Fleet Manufacturing, of Fort Erie, a leading producer of fabricated skin components and sandwich structures, is noted also for the design and development of light-weight, refined aeronautical structures.

As might be surmised from this discussion, the bulk of the R & D facilities in the air-

frame industry is to be found in Canadair and de Havilland. Excluding the usual laboratory equipment necessary for inspection and quality control, and that required for the normal testing and development of aircraft, most facilities at Canadair are for structural testing. At de Havilland the picture is rather similar. The emphasis has been on *ad hoc* rigs for the static and dynamic testing of airframes and components. De Havilland has a small aerodynamic testing facility for the development of jet devices and other items but, as with Canadair, the bulk of all aerodynamic experimentation is carried out in wind tunnels provided at the National Research Council, in the earlier stages of project development, and in company-directed full-scale flight tests at the later stages. Both de Havilland and Canadair have experimented to a limited extent with ground-based and airborne simulators and towed, ground-based test vehicles.

Aero-engine Companies

There are two major engine development programs active in Canada, both based on gas turbine technology. One is at Orenda Engines Ltd. and is directed towards industrial gas turbines—mentioned here because of the very close relationship it bears to aircraft engine technology. The other is at United Aircraft of Canada and involves small gas turbines primarily for use in aircraft. A third aero-engine company, Rolls Royce, has a modest research and development program.

The Orenda program utilizes the expertise that was acquired when the company was developing aircraft engines. In the initial venture into the industrial power-plant field, the company adapted aircraft engines to provide the power for pumping natural gas and generating electricity. Subsequently, engines were specifically developed for these functions, and at the present time the company is marketing five models ranging from 1 650 to 10 650 h.p. and has under development a 15 000 h.p. and a 23 500 h.p. engine. The total market for this type of engine in terms of delivered horsepower increased by a factor of fourteen between 1960 and 1967 and continued rapid growth is predicted.

The small gas turbine development program at United Aircraft started with the PT-6 turbo-propeller engine. Over 3 000 of these engines have been delivered, of which 77 per cent were directed into export markets. In its power class this engine captured 74 per cent of the

available market. The company currently has under development four new versions of this engine, having increased horsepower and particular configurations to satisfy orders from specific customers. One of these is the *Twin-Pac*, using PT-6 engines, for a helicopter application. The engine has also been adapted for industrial applications with some success. It should be noted in passing that a technically successful small aero-engine is unlikely to be developed into a technically successful large engine. In other words, there is a limit above which the output of a particular small engine cannot be pushed without it becoming another engine altogether.

In 1962 United Aircraft initiated a research program on centrifugal compressors and, subsequently, one on radial turbines, in the interest of generating the technology to develop simpler lower-cost engines. It is believed that the current technology in the company is equal to or surpasses that of its competitors. The first application of this knowledge is being used in the development of the JT15D turbofan engine which was started in 1966 and for which orders have been received from two foreign commercial customers.

As regards facilities, Orenda is equipped with test cells for the power ranges needed for its current development program and has other facilities such as component test rigs and sophisticated laboratory equipment. The R & D facilities of United Aircraft have been valued at \$5 million and are generally well suited for the company's needs. They include 11 development cells, two flying test beds and numerous rigs and other devices. Industry also receives support from the National Research Council through the use of its laboratories for routine engine tests as well as assistance on specific projects. The latter includes analytical and experimental work on combustion, vibration and metallurgical problems which have been requested by industry.

Aero-engine development programs in industry are strongly influenced by market conditions. Although there are less than a dozen companies in the western world engaged in aircraft gas turbine development, of which three or four are in the small engine class, these companies compete vigorously in their own countries and internationally. The international commercial market, although influenced to a degree by tariffs and political considerations, is characterized primarily by the traditional elements of cost, time and per-

formance. Government policy in the industrialized countries tends to deter, but not to exclude, foreign intrusions. A final conclusion is that the potential market for aero-engines is dependent on the needs which airframe manufacturers visualize for *their* products.

Successful engines have historically remained in production for protracted periods and the manufacture of spare parts can double or triple the time span. The longevity of a program is dependent to a large degree on a company's ability to respond to opportunities which require variations in model configuration or performance and is of obvious importance in recouping development costs. Commercial customers in particular expect to be provided free use of prototype engines for aircraft testing at a cost to the developer which is three to four times that of a production engine.

Successful engine development demands sizeable commitments in manpower, material and facilities for a period of time that extends well beyond the delivery of the first production article. Adequate long-term resources must therefore be available not only to consummate the original intentions but also to improve the basic characteristics, reliability, power, fuel consumption, weight and cost. These resources must also provide the flexibility needed to satisfy new market considerations. In engine design and development, the latter activity is perhaps more important than the former and this reflects one of the several differences between the airframe and aero-engine businesses. In fact the two industrial activities are so different that they require different "prescriptions". Nevertheless, as in most high technology industries, the orderly development of a product is dependent on the availability of relevant research data. The research work must therefore lead its application by several years and should be maintained on a continuing basis to be of significant use.

All the major companies throughout the world which are developing aircraft gas turbines receive assistance from their governments. This assistance may be in the form of complete funding, typical for domestic military projects, grants, loans, or tax concessions. With the reduction in Canadian military projects that has taken place during the past decade, companies engaging in research and development have received, for the most part, partial government funding through the various industrial support programs. Companies in other countries con-

tinue to be the recipients of funded military programs which encompass R & D, production tooling and start-up costs. Military engines, unlike most military aircraft, can be—and have been—adapted to commercial and industrial use. These products have an obvious price advantage in an international market. Canadian government policies concerning future assistance programs for the aero-engine companies might be formulated against this kind of background.

Avionics and Accessories Companies

Historically, the avionics and accessory equipment manufacturers have been largely dependent for their business on the product design philosophies and on the marketing successes of the aircraft and power-plant manufacturers. Their product goals, research and development objectives, and investment policies have been based on the probability of near-term success and the future prospects of these latter companies.

As a result of the falling off of government-supported manufacturing programs in the aircraft and power-plant sections of the industry, there has recently been a realignment of business objectives of the aviation industry as a whole away from the domestic market and towards the export market. This, in turn, has affected the R & D objectives of the individual companies making aircraft accessory equipment. This recent emphasis on exports has, however, strengthened the business positions of those accessory companies having strong R & D capabilities. Foremost amongst them have been the avionics companies which have taken advantage of innovative "fall-out" from R & D activities and of various kinds of government support to boost considerably their export market penetration.

As far as avionics and accessory equipment is concerned, the costs of innovation are very difficult to assess or forecast. In addition to R & D expenses, the costs of regulatory qualification and marketing a new equipment concept have to be included. There may also be sizeable capital investments involved. But those companies which have a "tie-in" with a dominating commercial product—such as a particular type of aircraft—may plan their R & D expenditures with some assurance of an eventual return from the investment. In reverse, the lack of a "tie-in" will have adverse effects on the R & D-innovation process in many cases.

The avionics and accessory equipment manufacturers are concerned about the need for greater government participation in this process as a whole.

The following are comments on the research and development activities in selected avionics and accessories companies.

Aviation Electric Ltd., at Montreal, has underway in-house R & D programs in gas turbine fuel control systems; fluidic sensors, devices, circuits and systems; and military vehicle navigation systems. The company's R & D expenditures on fuel control systems have already been profitable in terms of sales to United Aircraft of Canada of all the systems required for new versions of PT-6 engines—the *Twin-Pac* for helicopters, the A-50 for the multi-engined DHC-7 STOL airliner, and also for the JT-15 engine program. The company's fluidic sensors and devices are currently undergoing evaluation and are expected to be applied widely in the aerospace field, including aircraft and missile control systems, aircraft environmental control systems, and turbine engine control systems. Research and development work on automatic position reporting systems is currently in progress as an extension of the vehicle navigation system work.

Bowmar Canada Ltd., at Ottawa, is continuing its in-house work on precision rotating components. The company also has a major R & D effort in solid state display instrumentation which has attracted financial support from the United States Air Force and from major U.S. prime contractors.

CAE Industries Ltd., at Montreal, is continuing its research and development work on magnetic anomaly detection (MAD) instrumentation. One important new product is in the advanced prototype stage and another is in the process of being reduced to hardware. These products are being aimed at export rather than domestic markets. This company maintains R & D effort on a continuous basis in support of the development of its very important flight simulator business. Recent work in this particular field has led to the conversion from analog to digital computation methods as the basis of the simulators. Some of the current and future work will attempt to refine the new technique. Most of this work will be concentrated on the visual and motion systems of simulators.

Canadian General Electric, at Toronto, also has a continuing research program in avionics

concerned with signal processing as applied to radar sensors. This program involves both optics and electronics and will be applied to airborne surveillance radar systems (such as AWACS), sidelooking ground map reconnaissance radars, and weather penetration radars for both airborne and ground systems. This company is also active in the development of communications equipment and radar system components for air traffic control applications.

The Canadian Marconi Company, at Montreal, is continuing the R & D work on its already successful airborne doppler navigation systems. New activities in avionics are underway in several of the company's product areas including low-level altimetry—which has now reached the flight-test stage, tape indicators, hybrid navigation systems, and navigational computers.

Canadian Westinghouse, at Hamilton, has a broad range of on-going research and development programs in many aspects of electronics. There are, for example, a number of projects in areas such as integrated circuit technology, electroluminescence, alphanumeric display systems, stabilized platforms, and control systems. In view of the declining military market, the particular projects have been selected principally for their applicability to both civil and military markets. Over the past several years, this approach has resulted in the development of products such as TOTEM, a surveillance device for the military market, and WESSCAM, a stabilized device for airborne film making—both of which use the same basic technology. Current work is expected to lead to airborne surveillance and film camera systems, low light level aircraft lighting, components for airborne electronic systems, electroluminescent instrument panels, and pilot training aids.

Computing Devices of Canada Ltd., at Ottawa, has planned its current R & D program in support of its established avionic product lines. Earlier R & D resulted in the eventual sale of projected map systems (PMS) to the U.S. Navy for the LTV A7E *Corsair* aircraft. Current work in this particular area is being directed towards fully self-contained PMS systems for helicopters and for airline area navigation applications. The company is also developing a "combined display" which will present film-projected map images and (or) superimposed cathode ray tube images or symbols on a single display screen. The company is also developing a digitally programmed

automatic test set for PMS, and this equipment will be used for field maintenance primarily on board aircraft carriers. Finally, a new avionic program is underway for the development of a gross thrust computer system for gas turbine jet engines. The program includes the development of continuous instrumentation and the digital solution of thermodynamic performance equations.

At EMI Electronics Canada Ltd., of Dartmouth, Nova Scotia, the current R & D program in avionics includes work in the following areas: the development of automatically deployed, air launched, moored buoy systems for air-sea warfare, oceanographic and meteorological applications; the development of advanced digital ADF systems; and the development of lightweight radar transponders.

Ferranti-Packard Ltd., at Toronto, has avionic research and development in only two areas at the present time. For the civil aviation market, the work is concerned with the development of both manually operated and computer-controlled displays based on the company's proprietary basic electromechanical system. For the military market, the company is developing an experimental saddle coil superconducting magnet with a very large field volume but of minimum weight.

Garrett Manufacturing Ltd., of Rexdale, Ontario, maintains continuous in-house research and development programs in the fields of temperature control systems, programmable pneumatic signal generators and other electromechanical equipment, power conversion equipment, specialized communications equipment, and thin and thick film microelectronics. Past R & D activities have made the company a major supplier in the free world of temperature control systems for highly sophisticated aircraft. The most recent contracts awarded have been for the Grumman F-14A, the McDonnell-Douglas DC-10, and the Boeing 747 and 2707. The company's most recent development in the power conversion equipment field has been the 250VA commercial unit which has just received the U.S. Federal Aviation Agency's TSO approval. The company has also become one of the major producers of pneumatic signal generators for commercial and military aircraft check-out. The latest developments include computer-programmed generators for the checking of flight instruments and pitot static systems for the BAC-Sud Aviation *Concorde* and for the U.S. Navy's VAST program. A

portable programmable unit with read-out recorder is also being produced for the LTV ATD/E aircraft.

Leigh Instruments Limited, at Carleton Place and Ottawa, has extensive current R & D programs in the following product areas: crash position indicators (CPI); flight data recording systems; altimeters and aircraft instrumentation; and automatic direction finding systems. The CPI work is being directed to system improvements in response to new military markets for the device. Work is also being done to develop a family of these devices for application to commercial, business and private aircraft. Commercial versions are in the prototype and preproduction stages. Flight data recording systems are being further developed to improve performance and to reduce weight and size for application in new high-performance aircraft for both military and commercial markets—which have different requirements. A servopneumatic altimeter is currently being prepared for quantity production and a series of variants of the basic unit is being developed in response to new market requirements. There are promising commercial and military markets for this type of instrument.

Litton Systems (Canada) Limited has a number of research and development programs in areas which are in general closely related to its product lines. A continuing research in gas-spin bearing technology has an important influence on the company's capabilities to engage in quantity production of the latest type of advanced inertial systems. The company is also engaged in a fundamental research program which is concerned with the basic philosophy of digital computer design. Yet another program deals with studies of an optical character recognition system and its application to the field of electronic data-processing. Other interests of the company are directed to possible civil applications of the data-processing and display technology which has been acquired through the manufacture and operation of the CCS-280 Command and Control System for the Canadian Forces (Maritime). Of major importance is a program for the development of an area navigation system utilizing the latest inertial sensor and digital computation technology. This is aimed essentially at the commercial aviation market and is a logical extension of the company's current activities in the production of LTN-51 commercial inertial navigation systems.

The Aircraft Products Division of Uniroyal Ltd., at Montreal, has current in-house R & D programs in two areas: improved fuel tank materials and construction to meet the more advanced aircraft requirements of the future for both bladder and self-seal types of fuel cells; and improved crashworthy fuel cell construction to meet higher g-load crash resistance requirements in helicopters.

Government Assistance Programs *

Manufacturing companies within the aviation industry in Canada have been able to take advantage of a number of federal government incentive and assistance programs designed to increase their research capabilities, technical competence and market potential.

The first of these programs was established in 1959 to complement the U.S.-Canada Defence Production Sharing Agreement. Its aim was to sustain and improve the development capabilities of Canadian companies active in the military product field. Development project costs were to be shared and the companies were expected to contribute about half of them. Initially, the program was financed and administered by the Department of Defence Production. Later it became the responsibility of the Department of Industry, Trade and Commerce. The program has recently been revised and renamed the Defence Industry Productivity Program. During its first year of operation, expenditures by the government were less than \$2 million but, by 1967-68, industry had taken advantage of this program to the extent of \$23 million. Historically, about 70 per cent of the funds has been used for aerospace projects.

The Defence Industrial Research (DIR) Program was initiated late in 1961. This program has been the responsibility of the Defence Research Board. Its principal objectives have been to encourage industry to perform more research of an applied nature relevant to defence needs, to broaden the technical bases of the defence companies in this country, and to help these companies achieve the level of technical competence necessary to compete for defence business at home and abroad. This program was intended to complement the Defence Development Sharing Program. Costs are usually shared on a 50-50 basis, with the government covering the readily identifiable items such as direct labour and some material

or equipment charges. Projects in the field of aeronautics which have been, or still are being, supported under the DIR program include the following: STOL research at de Havilland Aircraft of Canada, including augments wing studies; materials, design-related, and lift/drag work at Canadair; compressor and turbine research at United Aircraft of Canada; and avionics and accessories work in a dozen or more other companies. Here again industry has recognized the advantages of such co-operative programs, the total funding in this case remaining around the \$5 million mark for several years. In fiscal year 1967-68, the aeronautical component of the expenditure was about 40 per cent. This continuation of the traditional support of the aircraft industry by the Department of National Defence has been extremely beneficial in the encouragement of advances and innovation in this industry.

The National Research Council's Industrial Research Assistance Program (IRAP) was initiated early in 1962 and is the civil counterpart of the Defence Industrial Research Program. IRAP was designed to encourage longer term applied research in all sectors of Canadian industry and particularly in companies in which these activities were at a low level or nonexistent. Once again the costs of each project are shared about 40-60 by the government and the companies, with the National Research Council paying staff salaries and fringe benefits. Like DIR, the individual projects approved under IRAP have had to be initiated by the companies. But, unlike DIR, the IRA program requires that the projects should represent additions to company R & D activities. By fiscal year 1967-68, the total funds utilized by industry through IRAP were approaching \$6 million, of which aircraft accessories and avionics manufacturing companies received only about \$80 000.†

Under the Program for the Advancement of Industrial Technology (PAIT), the government shares with industrial firms the cost of specific development projects, including the cost of the special equipment and prototypes required to achieve or demonstrate technical objectives. In the event of a project being both

*This section will describe the main programs only.

†It must be remembered that the aircraft industry has made extensive use of the research facilities operated by the NRC and that, in general, this industry has felt that other government co-operative programs have met its needs more appropriately than IRAP.

technically and commercially successful, recipient companies are obliged to repay the government's contribution. Established in 1965, the PAIT program is currently the responsibility of the Department of Industry, Trade and Commerce. The objectives of the program are:

- to increase the level of productivity and to improve the competitive position of Canadian manufacturing industry;

- to take advantage of Canada's natural resources, skills and environment to establish a unique capability or technical leadership;

- to reduce the dependence of Canadian manufacturing industry on foreign technology; and

- to create an industrial environment in Canada which is attractive to highly trained scientific, technical and managerial personnel.

During the fiscal year 1967-68, industry utilized the PAIT program for aerospace projects to the extent of some \$2.7 million. This represented about 40 per cent of the total amount used by all industry through this program.

Since 1944, companies in Canada have been allowed to deduct a portion of their expenditures on "scientific research" from their taxable incomes. The rules governing the eligible portion have been changed from time to time but, in 1962, had reached 100 per cent of all capital and operating expenditures. But in 1962, the federal government introduced a special tax-based incentive provision under which companies could deduct a further 50 per cent of those expenditures on R & D made in Canada which exceeded their 1961 base-period expenditures. This tax-based program was in operation for the taxation years 1962 through 1966 when it was replaced by the Industrial Research and Development Incentives Act, which has become known as the IRDIA program. The primary objective of IRDIA is to induce Canadian corporations to expand those R & D activities which are likely to result in economic benefit to Canada. The Act provides for taxable corporations to receive, annually, cash grants or credits against federal income tax liabilities equal to 25 per cent of all allowable capital expenditures and 25 per cent of the increase in current operating expenditures for R & D in Canada over the average of these expenditures for the preceding five years. Grants made under the Act are not subject to federal income tax and are in addition to the 100 per cent deduction

already permitted under the Income Tax Act. To qualify for a grant, research and development work must be carried out in Canada and, if successful, must be likely to lead to, or to facilitate, an extension of the business of the corporation in this country. A total of just over \$2 million was applied under IRDIA in the form of grants or credits during the government's 1967-68 fiscal year. Of this, the aerospace industry applicants received just over \$210 000. It should be noted, however, that these grants largely reflect expenditures made by the companies prior to the beginning of the fiscal year in question.

Research and Development in the Universities*

A survey was conducted to determine the extent of participation of Canadian universities in aeronautical research and development during the academic year 1968-69. To obtain a proper assessment of current research programs, a representative list of participants was prepared from NRC and DRB lists of grantees and from information provided by university deans and department chairmen. A spectrum of replies was received ranging over:

- a) work specifically in aeronautics;
- b) projects with some application to the field; and
- c) research not related to the field.

A total of 127 replies were received, of which 36 were judged to be in category (a), 26 in category (b) and 65 in category (c), the views of the respondent being taken into account. In general, the results show that a fairly wide range of aeronautical research is proceeding in Canadian universities. The two major centres for such research are the Institute for Aerospace Studies of the University of Toronto (UTIAS) and the Department of Mechanical Engineering at McGill University, Montreal. Certain departments of mechanical engineering at other universities across Canada also give some limited attention to the subject.

The survey indicated that the list of topics currently under study is an extensive one. Aerodynamic studies form a significant part of university research programs and cover

*The work on aviation medicine at McGill University has *not* been included in this section. It appears later in the section "Aviation Medicine and Physiology."

such areas as flight in a turbulent atmosphere; flow noise; problems relating to V/STOL and air cushion design; fluidic technology; laminar and turbulent boundary layers; jets and wakes; jet-flap systems; bluff bodies; flight in a rarefied atmosphere; supersonic boundary layers; and the hyper-sonics of real gas flows. Propulsion is a second major area of research. Typical subjects are the steady and unsteady combustion of composite propellants; energy transport in hot combustion products; flame stabilization; heat transfer to curved surfaces with adverse pressure gradients; gas turbine thermodynamics; methods for predicting the components of turbo-machine losses; hyper-sonic air-breathing propulsion; properties of plasmas; and energy conversion. Somewhat less attention is being given to structures and materials. Typical projects include the stability of thin shell structures; stress in sandwich panels with cut-outs; dynamic properties of materials subjected to high rates of loading; fatigue crack propagation; and natural frequencies and modes of vibration of structural elements. The promising current work on the application of lasers to fog dispersal and the detection of clear air turbulence can be mentioned to illustrate the development of new diagnostic techniques emerging from universities in the field of avionics.

The extent of the university program of research in aeronautics is further indicated by the calibre of major facilities in use. There are, for example, numerous low-speed wind tunnels in use for particular purposes. A pilot model of a newly conceived turbulence-controlled tunnel is under detailed test. Tunnels, shock tubes and launchers are available for studies of upper atmospheric phenomena, supersonic flight and hypersonic flow. An anechoic chamber for jet noise studies and a simulator for human pilot-dynamics illustrate the diversity of the equipment being used. Combustion research facilities, gas turbine test rigs and shock tubes for the study of chemical kinetics and combustion chemistry are available in the propulsion field. Extensive use is also being made of photoelastic equipment and fatigue testing facilities for the study of materials.

A detailed breakdown of the extramural grant support for university research in aeronautics in Canada, which was identified during the survey, is given in Appendix 12 of this report. These statistics do not include the

salaries of professors and others which were paid from university sources and which could be charged, in part at least, to aeronautical research work.

The survey also produced an interesting comparison between the mission-oriented, university-based institute—which is committed to hardcore aeronautical research—and the traditional, generally discipline-oriented, university department engaged in a range of activities of which aeronautical research is only one. For example, with regard to category (a) activities, as defined earlier, the average number of graduate students per staff member for UTIAS is close to five, while the average for all university departments qualifying under this category is three, indicating that supervisors in the departments are probably more heavily involved in non-research duties. Again, a comparison made on the basis of grant income per supported graduate student or postdoctoral fellow, for category (a) work, in all eligible university divisions shows the average figure to be in the neighbourhood of \$5 600. Although the figures for both the University of Toronto Institute for Aerospace Studies and the Department of Mechanical Engineering at McGill come relatively close to this level, UTIAS receives only half and McGill three quarters of their support for these research workers from Canadian government agencies. With a few exceptions, such as McMaster and the University of Western Ontario, all other departments depend essentially on the National Research Council and the Defence Research Board to fully fund their research in aeronautics. The ability of UTIAS and McGill to attract funds from other sources is also strengthened by their research facilities. The equipment investments per *principal* investigator are in the region of \$140 000 at UTIAS, and \$49 000 for McGill, as against \$21 000 on the average for all the other departments. This evidence suggests that UTIAS—and to a lesser extent McGill—have reached a “critical group size” such that a supervisor can concentrate entirely on aeronautics in a stimulating atmosphere created by an adequate number of associates with a resultant increased output of students. The cost to the federal government per research worker is less because many funding sources can be opened up, and a wider range of high-performance facilities is available to support aeronautical education and research on an adequate scale. The distribution of federal funds to support aeronautical research in the

universities should reflect a recognition of the important role of the centre of excellence. The Study Committee concludes from the foregoing discussion that where the universities are concerned, for mission-oriented projects it would be beneficial to have more research going on in fewer places.

The contribution of the Canadian government to the funding of aeronautical research in the universities has come primarily through the grants committees of the National Research Council and the Defence Research Board. Considerable support has come from NRC as a result of recommendations from its Grant Selection Committee for Mechanical Engineering, the membership of which is composed entirely of university professors supported by three conveners from the NRC staff. The Defence Research Board channels its contributions to aeronautics essentially through the Advisory Committees on Materials Research and on Plasma and Gas Dynamics Research with membership drawn from government, industry and the universities.

At UTIAS, McGill, McMaster and Western, sources of additional funding have been found in mission-oriented agencies of the United States government. These funds arise from unsolicited research proposals initiated by the university laboratories. Grants are obtained in competition with U.S. universities and this ensures that the research is original and of high calibre. Research workers on U.S.-sponsored projects may also be supported by the National Research Council or Defence Research Board. Personal contacts made possible by U.S. grants have led to a close liaison on current research with American laboratories. In particular, the so-called "contractors' meetings" have permitted open discussion of prospective research programs and the establishment of priorities for future work.

The survey has shown that no research group in a Canadian university has been able to attract significant funding from the Canadian aeronautical industry. This is not because there is no contact with industry. Indeed, many university supervisors engage in consulting or accept summer appointments in the Canadian aircraft industry. Consulting work is done largely in fields of particular interest to industry and is particularly active if the consultants' own projects are being conducted in close proximity to the aircraft industry. It is possible that

university-based industrial research institutes initiated by the Department of Industry during the past four years may lead to an improved level of co-operation between universities and industry. These institutes undertake to solve industrial problems on the campus on a contract basis.* A different concept has been adopted at the University of Toronto Institute for Aerospace Studies. This Institute has recently begun a co-operative research program with a Canadian aircraft company aimed at helping the industry to help itself. Under this particular program, UTIAS will provide the basic requirements for a new department for research and development in the company by training required personnel, designing and constructing specific research facilities for transfer to the company, providing needed research results in the interim, and engaging in consulting work to support the company on a long-term basis. This arrangement has also led to graduate thesis topics of a high calibre, and a new area of research closely associated with Canadian needs has been established at UTIAS. Funds to support this co-operative research program were made available to the company through the Advisory Committee on Defence Industrial Research.

Aviation Medicine and Physiology

Research in aviation medicine and physiology is conducted at three locations in Canada: the Canadian Forces Institute for Environmental Medicine (IEM) in Toronto, the Defence Research Establishment, Toronto (DRET), and the Aviation Medical Research Unit of the Department of Physiology at McGill University, Montreal.

The Institute for Environmental Medicine comes under the Surgeon General, within the Personnel Branch of the Canadian Forces. It is responsible for research, development and teaching in the field of human factors as they relate to military systems. It is composed of three parts: the School of Aviation Medicine; the Central Aircrew Medical Board; and the Operational Medical Establishment.

The School of Aviation Medicine provides instruction in aviation medicine and the application of physiological research methods.

*Institutes have been established to date at the Universities of Windsor and Waterloo, at McMaster, and at the Nova Scotia Technical College.

It also reviews and advises in aeromedical training and maintains liaison with other schools of aviation medicine. Reflecting the Institute's broad responsibilities for work in military environments other than air, the School of Aviation Medicine also covers underwater and field medicine. The School is providing aviation physiology training to civilian organizations such as flying clubs. The demand for training of this kind has "exploded" from 18 students in 1966 to 260 students in 1968. At present, the School cannot satisfy all the demands made on it.

The Central Aircrew Medical Board provides assessment and advice on the medical condition of aircrew and reviews methods of examination and medical standards. One of the most important aspects of the work of the Board is that of dealing with carefully selected people who can be studied continuously during their Service careers. Psychological motivation and its components (e.g. stress and fatigue) are of particular interest to the Board, and the "critical instance technique" is being used to study certain aspects of motivation.

The Operational Medical Establishment investigates and makes recommendations on the human factors related to efficiency within the Canadian Forces. It also does investigative and development work in applied science, maintains liaison with similar research groups in university and industry, and trains selected personnel.

Current research projects at the Institute for Environmental Medicine include studies of survival and rescue equipment, such as aircraft ejection seat packs, life jackets and life rafts, and of personal protective equipment such as helmets, oxygen equipment and anti-g suits. In the field of "human engineering", studies concern the work space in military aircraft, the incidence of fatigue in long-range aircraft crews and the problems of instrument flight transition in helicopters. Applied physiology studies are related to the mechanics and control of respiration, work capacity and physical fitness, disorientation and acceleration effects, acclimation to altitude and low temperature.

At the Defence Research Establishment, Toronto—formerly the Defence Research Medical Laboratory—the capabilities and limitations of man in a military environment have been studied for nearly 20 years. As at the Institute for Environmental Medicine, only a portion of the work of the Establish-

ment is concerned specifically with aviation medicine. The work falls mainly under two main groupings: physiology and human factors.

The work on vestibular physiology is of major significance for both military and civil aviation. In these studies, the effects of angular and linear accelerations—separately or combined—in inducing disorientation of pilots and motion sickness are being investigated. Major advances in the understanding of disorientation have become possible as a result of this work. Other studies in this area are concerned with climatic physiology and in particular, for aviation interests, the tolerance to cold stress. In the human factors studies, significant work is now proceeding on problems faced by pilots who must navigate at very low levels with great accuracy and at slow speeds. Another continuing program deals with auditory research and the human capability to discriminate auditory signals in the presence of broad-band noise. Important work is also being done on the conservation of hearing and the measurement of sound attenuation characteristics for various devices designed for hearing protection. Other areas of interest pertain to research on vision and the effects of eye movement, to pressure physiology (i.e. decompression), and to instrumentation for underwater diving operations. The Defence Research Establishment normally receives few firm requests for work from outside agencies or industry. One of its main tasks, therefore, has been to maintain its research teams intact, to upgrade their abilities, and to search for possible applications for the new information generated.

The Aviation Medical Research Unit at McGill University had its beginnings about 10 years ago when the Defence Research Board was asked to consider the provision of support for extramural research units in the universities. The McGill Unit was inaugurated in 1961 under the joint auspices of the Defence Research Board and the McGill Department of Physiology. The Unit is now located in the new McIntyre Medical Sciences Centre at McGill University.

The objective of the Aviation Medical Research Unit has been to build a research facility integrally related with the Department of Physiology and engaging in both basic and applied research programs in the general field of the neurophysiology of sensory-motor biological systems. The intention has been to pursue research having a bearing on defence

interests, but on a broader base than would normally be considered suitable in an intramural laboratory. Also, the Unit has been a source of well-trained graduate students who, in the event of a national emergency, could provide skills relevant to defence research programs.

At the present time, the Unit is conducting seven separate and continuing research projects ranging from the detailed analysis of excitatory and inhibitory processes at the level of single neurones in neural pathways of the brain to flight experiments in which the special impact of the flight environment is examined in man. A special feature of the Unit's work in every one of its projects has been to attempt to maintain an effective bridge between basic and applied approaches to the study of a problem area. Frequently it has been found that the outcome of a basic study has suggested a new applied approach, and vice versa.

Currently, the Unit's staff includes its Director and Assistant Director—who both hold appointments in the Department of Physiology—and a junior staff of five graduate students and four technicians. The Unit's research grants for the current year include a basic DRB grant of \$60 000 to cover essential expenses such as salaries and occasional new items of equipment, and personal research grants amounting to about \$21 000 awarded to the Director and the Assistant Director from DRB and the Medical Research Council respectively. Also, at present the Unit includes a serving officer on the strength of the Institute for Environmental Medicine who is pursuing a graduate research program in a field related directly to the problems of orientation in flying.

Aeronautical Research Sponsored by the Department of National Defence

When the National Aeronautical Establishment (NAE) was created, its terms of reference included the provision of appropriate facilities and research support for both civil and military aeronautics. Furthermore, it was assumed that the NRC Division of Mechanical Engineering would provide similar support in its areas of activity concerned with aeronautics. Therefore the Defence Research Board has not undertaken any significant projects concerned with airframes, aero-engines, structures, flight dynamics, fuels and lubricants and related areas. How-

ever, the Defence Research Board did undertake a broad program of telecommunications research at its Communications Research Centre in Ottawa which was relevant to aircraft communications. This Centre was recently transferred to the new Department of Communications.

The Defence Research Analysis Establishment (DRAE) has a major component operating in direct support of the Vice Chief of the Defence Staff's Branch; a portion of this component consists of a Directorate of Air Operational Research (DAOR). The Directorate is concerned with studies of air defence capabilities, the performance of radars, North American air defence, strike operations, systems requirements for tactical air operations and studies of air transport operations. All these projects involve systems analysis related to the performance and capabilities of present and future air operations systems. These studies are done in support of requirements definition, force structure, operational effectiveness, etc.

Aeronautical Research in Support of Civil Aircraft Operations

To all intents and purposes, the civil operators do no research but almost all of the larger ones do a certain amount of development in their efforts to be as self-sufficient as possible. The airlines rarely contract for R & D services since they consider that it is the responsibility of the manufacturer to improve his products and of the government research establishment to conduct research for the benefit of the public and industry at large. On occasion, the major airlines in the United States and Canada have made cash contributions to a fund for some specific research or development when it became apparent that certain pieces of work would not otherwise be done expeditiously.

The National Research Council, on its own initiative, is conducting a number of research programs which will benefit civil and commercial aviation, the manufacturers, the Department of Transport and the travelling public. Examples of such programs are:

- Accident prevention which includes studies of bird hazards to aircraft, bomb detection, "human engineering" factors, fractograph techniques in the analysis of failure of metals, and the investigation of clear air turbulence;

- The development of a "fly-away" crash position indicator;

-The development of oxidants and anti-oxidants.

The research and development activities within, or sponsored by, the Department of Transport are related primarily to civil aviation operations. Presently there are a number of studies underway in air traffic control including, for example: computer simulation of control problems for development of an optimum approach to separation, to expedition of traffic, and to the location and use of navigation aids; equipment development for real time data-processing and display; and equipment development for radar data-processing and display. With regard to navigation aids, studies are being conducted into area navigation systems such as Omega and OPLE, which are under development in the United States, and the Department is participating in Canadian Arctic applications. Companion work has been undertaken on VHF propagation in the Arctic. Work is also proceeding on problems associated with landing surfaces. Accident investigation techniques and procedures are under constant study. Meteorological studies and developments include the measurement, analysis of and reporting procedures for the Canadian atmosphere from ground level to beyond the tropopause, and include the use of satellites and radio techniques to understand and predict atmospheric phenomena including shear, gust and turbulence. Ice reconnaissance from specially equipped aircraft is also included in the meteorological studies. Airworthiness requirement studies and aircraft development work are not undertaken by the Department of Transport, except for the occasional request made to the National Aeronautical Establishment to assist with the investigation of a material, manufacturing process, or design concept which is novel or untested and unacceptable for aircraft certification.*

*The CRC has begun some research into civil aircraft operations but, at present, the bulk of this work is economic in nature. Some comments on CRC were made in Chapter IV above.

Summary

In Chapter I the Study Committee indicated the range of subjects and the broad activities which it proposed to examine, and some seven specific areas were identified as targets for the Committee's main interest. Since the present chapter has reviewed the aeronautical research and development currently in progress in Canada it is considered of value to summarize this briefly, with a few examples, in terms of these seven areas.

Aircraft Structures

Apart from the interesting structural design work in the airframe industry, which is inherent to new aircraft development, there is a good deal of structural research going on in Canada, most of which is of a continuing nature. At the National Research Council this encompasses statistical studies of aircraft loads in flight, the dynamics of structures and their aeroelastic response. At Canadair, good facilities have been provided and advanced techniques have been developed for such work as the analysis of redundant structures. At de Havilland some interesting work has been done on the dynamics of undercarriages. In the universities the interest has been directed to the stability of thin shells and the stresses in sandwich panels with cut-outs.

Materials

The materials research conducted in Canada is very extensive in industry, government and university. Only a fraction of this work was reviewed by the Study Committee and was confined to that done in close association with aeronautical applications. At the National Research Council, work of particular interest included fractographic techniques in failure analysis, the studies of high temperature super-alloy coatings, deposition techniques and high temperature diffusion characteristics. In the aircraft industry, work is in progress on plastics reinforced with honeycomb and composite materials. University work includes the study of fatigue crack propagation and the dynamic properties of materials subjected to high rates of loading.

Aerodynamics

As might be expected there is a lot of aerodynamic research in progress in Canada in the three sectors—government, industry and

universities. The National Research Council does a great deal of applied aerodynamics to meet industrial requirements and this has included wind tunnel work on the augments wing, the flow of air about upswept fuselages and flow separation from inclined bodies of revolution. The Council's interests have also included theoretical work on transonic wing design, the aerodynamics of v /STOL designs, and studies of three-dimensional boundary layers with both suction and air ejection, and the study of the separation of such boundary layers in the presence of shock waves. In industry, extensive studies of high-lift wings are progressing and here the techniques have been analytical as well as experimental using wind tunnels and flight testing. Canadair has done extensive work in investigating the performance of propellers or rotors at low forward speeds and McGill University has also contributed work in this field. Typical of similar subjects of practical interest which have engaged the attention of the universities are v /STOL problems, flight in turbulence and the noise associated with air flow. In the more basic, but important, subjects of boundary layers (subsonic and supersonic), hypersonics of real flows and the stability of flow in the presence of adverse pressure gradients and with wall jets, the universities have continued to give leadership in the traditional manner. Such studies have added significantly to scientific knowledge and have formed important components of the teaching process.

Aircraft Propulsion

Economically important development work in the gas turbine field is progressing successfully in the aero-engine industry. This is supplemented by industrial research typified by such programs as the centrifugal compressor and radial turbine studies at United Aircraft of Canada. At the National Research Council, analytical and experimental work on combustion, and vibration and metallurgical work has been done for industry. In addition, research and development with particular reference to propulsion has been pursued on VTOL aircraft concepts. Noise suppression and de-icing and anti-icing work has also occupied NRC effort. In the university sector extensive work is being conducted on steady and unsteady combustion, the transport of energy in hot combustion products, flame stabilization, heat transfer, the thermodynamics of gas turbines and the

derivation of methods for predicting the components of turbo-machine losses. All of this represents an excellent mix of basic and applied research efforts.

Subsystems and Equipment

It would seem that the major, if not the entire, effort in this discipline is confined to the industrial sector. A sample list of the kinds of products under development reveals the broad scope of R & D in progress.

- Gas turbine fuel control systems. Fluidic systems.

- Aircraft hydraulic systems.

- Aircraft environmental systems.

- Aircraft navigation systems. Data-processing and display systems.

- Radars, radar systems including signal processing systems.

- Communication systems. Digital computers.

- Automatic test equipment.

- Flight simulators.

- Crash position indicators. Flight data recording systems.

Aviation Medicine and "Human Engineering"

At the Institute for Environmental Medicine the research and development programs include studies of psychological motivation including its components—stress and fatigue, the study of survival and rescue equipment and personal protective equipment. "Human engineering" interests are directed to such subjects as the work space in military aircraft, fatigue in the crews of long-range aircraft, and instrument flight transition in helicopters. Applied physiology studies include respiration, work capacity and physical fitness, disorientation and acceleration effects, and acclimation to altitude and low temperature. At the Defence Research Establishment, Toronto, the excellent past work in vestibular physiology and disorientation is continuing and other programs in auditory and visual research are worthy of mention. The Aviation Medical Research Unit at McGill has a number of projects directed to the study of the physiological effects of motion, ranging from flight experiments down to detailed studies of the cerebral-neural response.

Aircraft Operations

The National Research Council, largely on its own initiative, conducts a number of research programs directed to the solution

of operational problems. Examples are bird hazards to aircraft, bomb detection, physiological factors, and the investigation of clear air turbulence. The Department of Transport sponsors or conducts R & D activities also to assist civil aviation operations. These include air traffic control (e.g., the simulation of control problems, using a computer), navigation aids, radio (VHF) propagation in the Arctic, landing surfaces characteristics, accident investigation techniques, and meteorology. The universities are currently engaging in studies of similar importance such as the application of lasers to disperse fog and the detection of clear air turbulence.

Chapter VI

Current Canadian Organizational, Management and Advisory Structures for Aeronautical R & D

This chapter deals mainly with the federal government's current advisory structure for aeronautical R & D, but there will also be some discussion of the other structures in government as well as those in industry and the universities. It should be noted at the outset, however, that the government's advisory structure is the only one which brings together representatives of industry, the universities and government at the present time.

In this country, government involvement with the overall organization and management of aviation and with the seeking of advice regarding aeronautical research actually goes back 50 years to the establishment of the Air Board in 1919. This Board had broad powers to control all forms of aeronautical activities and to regulate civil aviation. Anticipating future requirements for aeronautical research, the Board asked the National Research Council to form an Associate Committee to advise in this field. This Committee was set up in 1920. In 1923, the functions of the Air Board were assumed by the Department of National Defence, but the Associate Committee continued to exist. Beginning in 1927, civil aviation was a designated responsibility of the Deputy Minister of National Defence. In 1936, this responsibility was passed to the new Department of Transport. The first of the National Research Council's own aeronautical research facilities were opened in the early 1930s. The Associate Committee and its technical subcommittees were allowed to lapse in 1948 after almost 30 years of service.

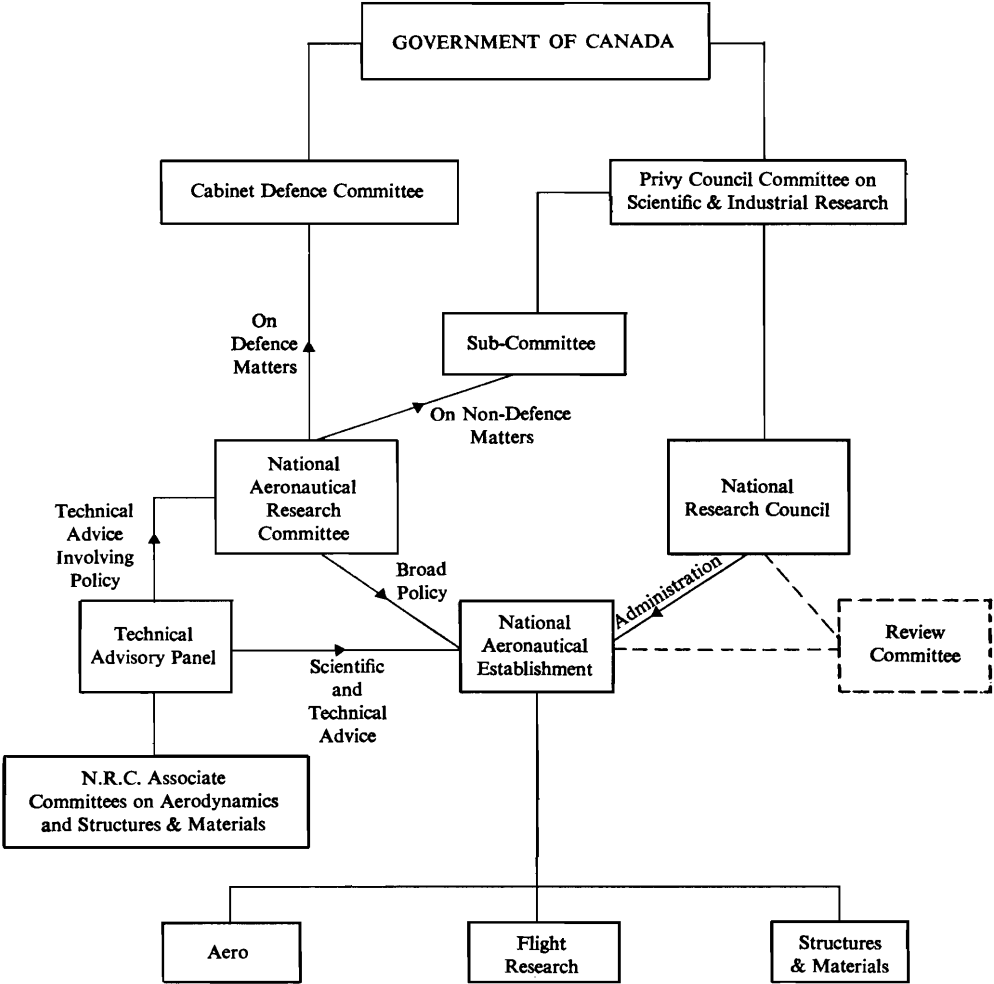
With the outbreak of the Korean War in 1950, an increased effort in aeronautical research was expected in Canada. At that time, military aviation was still regarded as the principal justification for work of this kind. It was agreed that the Defence Research Board—established in 1947—should assume control of the national aeronautical laboratories and should finance their expansion. It was thought that the research needs of civil aviation could still be met through this arrangement. The laboratories were renamed the National Aeronautical Establishment (NAE), but the National Research Council retained the administrative responsibility. The broad advisory responsibilities relative to policy issues were given to a new committee—the National Aeronautical Research Committee (NARC)—composed solely of senior government officials. The NARC and the Director of the NAE were to be advised on

scientific and technical policy matters by a Technical Advisory Panel (TAP). The original members of TAP were all senior government officials responsible for aeronautical matters in the various departments and agencies represented on the National Aeronautical Research Committee. The Committee was to report to the Privy Council Committee on Scientific and Industrial Research except in matters related to defence. These new arrangements became operational in 1951. In 1954, NARC gave the Technical Advisory Panel authority to establish technical specialist subcommittees, but no action was taken until six years later when three committees—on structures and materials, aerodynamics, and propulsion—were set up as Associate Committees under the administrative wing of the National Research Council.* A chart of this organization—as it was for many years—is shown in the following figure. Other committees were subsequently set up. All of them include representatives of the universities, government and industry. The full list of NRC Associate Committees which now have interests in the field of aeronautics is as follows:

- Aerodynamics
- Aeronautical Structures and Materials
- Agricultural and Forestry Aviation
- Aircraft Noise
- Aircraft Systems
- Avionics
- Bird Hazards to Aircraft
- Flight Safety
- Heat Transfer
- Propulsion.

Since the creation of NARC and TAP there have been a number of important events affecting their operations directly or indirectly. For example, in 1958, the decision was made not to proceed with the proposal to transfer control of the National Aeronautical Establishment to the Defence Research Board. In 1961, the terms of reference of TAP were expanded to include an annual review of all current aeronautical research in Canada and of the needs for new aeronautical research in this country. The membership of the Panel was expanded to include industry members and the Director of the University of Toronto Institute of Aerophysics, as it then was. With regard to the new research projects, the TAP

*The current constitutions of NARC and TAP and the terms of reference have been set out in Appendix 13.



Source: Report of the Royal Commission on Government Organization. Vol. 4, Sec. 23. Ottawa, Queen's Printer, 1963. p. 277.

established a *modus operandi* for itself in 1964 which included the following recommendations:

1. The Technical Advisory Panel should become a major clearinghouse for recommendations relevant to aeronautical and astronautical research in Canada. Although the Associate Committees are a natural source of technically evaluated proposals, the Panel should consider recommendations from all sources, either directly or through reference to the relevant Committee.

2. The assignment of priorities to these recommendations will be a major responsibility of TAP. A list of priorities should be available to anyone interested in undertaking work.

3. This list should be circulated to government, industrial and university laboratories for their information. The laboratories which are interested in any of the listed projects should first attempt to fund the work through their normal channels. For example, the National Aeronautical Establishment might do so through the regular NRC budgeting procedures and a university department might submit a proposal to the Defence Research Board or the National Research Council for support.

4. If an interested laboratory is unable to fund a project on the TAP list through the usual channels, this should be reported to TAP which, in turn, would then make a recommendation in its annual report to the National Aeronautical Research Committee. In this way, NARC could be assured that the required funds were not already available.

5. This procedure would not interfere with research project decision-making in individual laboratories, nor would it force TAP priorities on these laboratories. However, the TAP emphasis on a particular project could encourage and facilitate its inclusion in particular cases and help promote funding of new projects of national interest and importance.

Experience leading to the formulation of this *modus operandi* had been obtained in the case of the 30 ft. low-speed wind tunnel project. In May 1962, the Associate Committee on Aerodynamics concluded that an urgent need existed in industry for a large low-speed tunnel designed for research and development on v/STOL aircraft. A detailed proposal was presented for evaluation by TAP and the matter was given considerable further study before a recommendation favourable to the project was sent to NARC.

This committee approved the proposal in 1963 and specification and design work was undertaken by the National Aeronautical Establishment. Initial funding was provided by the Treasury Board in 1964 through the budget of the National Research Council. At the time of writing, the construction of the tunnel at Uplands Airport, Ottawa, has been completed and calibration and testing work are underway. In this particular case, special efforts were made to assess industrial requirements in detail and to involve *all* the interested parties in the final design. But in this case it must also be remembered that the National Research Council took responsibility for finding the necessary funds. Therefore, if a proposal lies within the area of interest of a particular government department—and especially one represented on NARC—the whole aeronautical research advisory structure at the federal level may work well. On the other hand, if the proposal should involve two or more departments with different interests, the structure may be much less effective.

During the course of its reviews in collaboration with the Associate Committees, the Technical Advisory Panel has made specific recommendations affecting the Canadian universities. For example, the particularly active Associate Committee on Aerodynamics recommended the study of subjects such as the interaction of a propulsive air-stream with a wing, the effect of large-scale low-level turbulence on aircraft stability and control, and the development of fluidic devices and air cushion vehicles. Some of these recommendations were subsequently adopted by the University of Toronto Institute for Aerospace Studies and McGill University and by a few other university groups. But, apart from the work of these groups, effective university participation in the solution of nationally important problems in the field of aerodynamics has not been achieved. In this case, the difficulties may be that the funding has to come from other government agencies which have no formal connection with, or responsibility to accept the advice of, the Panel or the Associate Committee.

The involvement of industry with aeronautical research and development projects originating within the NARC-TAP structure has been essentially nominal. In an assessment of the deficiencies between research requirements and current projects, the TAP recommended to NARC that industry should

become involved in such projects as the aerodynamic characteristics of high-altitude sounding rockets, the deterioration of metal-to-metal bonded joints, the application of fluid state devices to V/STOL stability augmentation systems, and aircraft windshield and automatic engine control research.

These projects were proposed by industry which possessed the research and development facilities to undertake them, and in some instances the facilities did not exist elsewhere. The Panel determined that the projects involved national requirements of public safety, health, law, or the establishment of national regulations related to technological practices, and recommended that they be fully funded by the National Aeronautical Research Committee or by a government department or agency, but NARC rejected this recommendation.* It therefore discouraged any substantial participation by industry in TAP-originated projects of a national character. According to its constitution, the Committee could have forwarded TAP's recommendations on industry to the Privy Council Committee on Scientific and Industrial Research for special consideration.

Presently, the National Aeronautical Research Committee is responsible for overall advice to the Canadian government on all policy matters relevant to aeronautical research and development. The NARC is required "to consider Canadian research programs and their relation to the national need" and "to endorse the implementation of approved proposals for new or re-oriented research programs, for new research facilities, or for industrial participation of appropriate kind". While the NARC-TAP organization has had some impact on the aeronautical work of the National Research Council, it has not had a perceptible influence on the direction of Canadian aeronautical R & D activities as a whole. It should be made clear, however, that NARC—in particular—has not been given guidance from the highest level on what this direction should be, nor has it received a clear mandate to implement it. To some extent, then, the failures of the system lay in the terms of reference of TAP and NARC which were concerned with research, not development, and it is now seen that co-ordination of the entire research and development effort is to be desired. It is perhaps not to be wondered that proposals involving industry "dropped into a vacuum" and produced no response.

The work of the NRC Associate Committees has, for the most part, been excellent. It has helped to minimize duplication and has brought industrial, government and university research workers to some understanding of problems of national interest. The work of the Technical Advisory Panel has been less effective in that it has lacked a clear mandate from NARC to pursue defined national objectives and has been concerned more with research than the whole spectrum of research, development and innovation.

The work of the National Aeronautical Research Committee has been seriously impaired by the fact that the Committee's membership has been limited to the administrative heads of government agencies, few of whom were necessarily active or experienced in aeronautical research—or committed to it on a personal basis—and all of whom had responsibilities above and beyond aeronautical research and aviation as a whole. The Committee has had no source of funds of its own and has not sought one. It has had no authority to influence *directly* the spending of money on aeronautical R & D activities even within the federal government. The Committee has not compiled or published on a regular basis a co-ordinated and future-oriented overview of the status of, and prospects for, aeronautical research and development activities in government, the universities and industry in this country or for innovation throughout the aviation industry as a whole.

Within the federal government, the organization and management of activities in aviation is determined by the various statutes, orders, and regulations, which govern the activities of the individual agencies and departments.† The aeronautical activities of these departments and agencies come under the purview of the various responsible ministers but, up to the present, little evidence

*Some of the above-mentioned projects did, later, receive attention—but not as a result of support by the NARC-TAP system.

†The Department of Transport, for example, is mainly concerned with regulation; the National Research Council with the performance of research and development and university support; the Department of National Defence and the Defence Research Board with national security problems; the Department of Supply and Services with procurement; the Department of Industry, Trade and Commerce with industrial production and markets and with the support of aeronautical development on a cost-sharing basis; and certain other Departments such as Energy, Mines and Resources with special applications in the field.

has come to light to show that aeronautical research and development activities are being satisfactorily co-ordinated within the government and within the country as a whole. The existing departments and agencies can—and do—seek advice from specially appointed or standing Advisory Committees and from specially convened Interdepartmental Committees.* Nevertheless, the mechanism for providing knowledge and understanding to government officials concerned with aeronautical matters does not always appear to be adequate at every level of decision-making. The Canadian Transport Commission has overall responsibility for the formulation of a national transportation policy. But activities associated with aviation are only part—and sometimes only small parts—of the areas of organizational and management responsibility of each of the federal departments and agencies. While it may be neither possible nor desirable to centralize all the government's activities associated with aeronautical science and technology in a single agency, it does seem that the establishment of a simple but effective co-ordinating mechanism, together with the necessary technical competence in the departments at each required level of decision-making, should help the departments and agencies to seek resource allocations appropriate to the achievement of their missions and objectives which involve aviation.

The research and development activities of the aviation industry are normally organized and managed at the level of the individual company or at the regional or international level in the case of groups of affiliated companies. Some companies have formally organized laboratories, while others include R & D with their design and engineering activities. The amount of R & D performed by the individual company or by the Canadian members of a group will depend on many factors, of which the dominant ones are the business each company is in and the market each serves. In the case of several Canadian subsidiaries of foreign-owned corporations, strong Canadian managements have sometimes been able to influence the size of R & D and production activities of their companies or their inherent technical competence, among other factors. The advisory structure for

aeronautical R & D within industry is usually a matter for the individual company or the corporate group, but industry-wide advisory activities in this country have been initiated by bodies such as the Air Industries and the Electronic Industries Associations and by specialist technical groups such as the Canadian Air Line Pilots Association.

Government assistance to aeronautical R & D in industry may take a number of forms. For example, the Department of Industry, Trade and Commerce is responsible for the administration of the Defence Industry Productivity Program (DIPP), the Program for the Advancement of Industrial Technology (PAIT) and the Industrial Research and Development Incentives Act (IRDIA). The Defence Research Board administers the Defence Industrial Research Program (DIR) and the National Research Council administers the Industrial Research Assistance Program (IRAP). These departments do consult with one another on matters affecting the support of industrial R & D at both the program and the project levels. In recent months, an Interdepartmental Committee has been looking into the effectiveness of government assistance and incentive programs with a view to making recommendations with regard to them. The Department of Supply and Services, the Department of Transport and the Department of National Defence, among others, are concerned with the aviation *products* of Canadian companies and, only indirectly with R & D activities in industry.

A substantial part of the current university program of aeronautical research in Canada is carried out at the University of Toronto Institute for Aerospace Studies (UTIAS) and within the Department of Mechanical Engineering at McGill University in Montreal. Another dozen or so universities—including departments of the University of Toronto other than UTIAS—also perform some aeronautical research, and there is research in aviation medicine at McGill. Most of the universities which are active in aeronautics are located in the provinces of Quebec and Ontario where most of the industry is based. The universities, as a group, have no co-ordinating or advisory structures of their own but individual staff members advise government departments and individual companies and help to guide the policies and practices of those agencies which support aeronautical research in the universities through contracts, grants, fellowships, and so on.

*At the present time, for example, an Interdepartmental Working Party is studying the problems of STOL aircraft in Canada.

Aeronautical research in Canadian universities is funded from foreign as well as Canadian sources. From the national point of view, the support comes principally from the Defence Research Board and the National Research Council.

There are also a number of independent organizations which have an active interest in aeronautical research and contribute principally to the organization and management of flying activities, to the collection, study and dissemination of new scientific and technical information and, indirectly, to the advisory structures within government and industry. Among these organizations are the Alberta Aviation Council, the various Flying Farmers' groups, the Canadian Owners and Pilots Association, and the Canadian Aeronautics and Space Institute which is the learned society in the field.

Broad national objectives for aeronautical research and development have not been formulated in this country except perhaps in the period immediately after World War II when it was decided that Canada should have an independent military combat aircraft design and development capability. Again, it may be neither possible nor desirable that an all-inclusive set of formal objectives should be adopted at the highest level. Nevertheless, the Government of Canada owns almost all of the major aeronautical R & D facilities in the country and facilities such as wind tunnels of various sizes are being legitimately used for research into both aeronautical and non-aeronautical branches of science and technology. Also, the existing facilities are used to a significant extent by industrial as well as government scientists and engineers, and this arrangement should be continued. There exists, therefore, the problem of determining how to use these facilities in the best interests of Canada and of aeronautical research.

It is clear that there are cogent reasons for the establishment of broad guidelines by the government with regard to aviation in this country. As a basis for this it is necessary for the government to receive advice on aspects of this subject on a continuing basis. For example, there may be a strong incentive to find new and more effective methods whereby the research in universities and the R & D in industry can be selected and supported on a more discriminating basis and with due regard for the achievement of established guidelines and objectives. Pres-

ently, the government provides support funds for aeronautical research and development in industry, in the universities, in NRC and in certain other government departments and agencies. Despite the fact that the financial support to industry and the universities has, in total, exceeded that spent in NRC and the other departments represented on the National Aeronautical Research Committee, the existing advisory structure has only exerted influence in the case of the latter group, not the former. It should also be noted that the relationships between the three principal R & D-performing groups—government, university and industry—have, at the senior level, developed in a haphazard way, except perhaps at the person-to-person level. Also, they have not always been placed in an overall framework which recognized the need for linking aeronautical research and development activities with the needs and problems of the aviation industry as a whole or with the challenges and opportunities which have faced aviation in Canada. The responsibility for this situation must rest with all three groups. The opportunity to remedy it, however, rests with the government.

Chapter VII

World Aviation in the Future

Military

It is difficult to predict future trends in the nature of military aviation since, apart from technological factors, they tend to be dependent on the changeable international climate and world power relationships. For example, the arsenals of nuclear weapons held by the major powers—and their threat of continental devastation—have helped to deter the outbreak of another major war and will probably continue to do so, but limited wars may continue to break out in various parts of the world. Against this background, there have been in most countries considerable political, social and economic pressures for the reduction of defence expenditures so that funds for urgent economic, social and environmental tasks might be released. Barring substantial changes in the international climate, it is possible that the world market for military aircraft will not continue to expand as rapidly as it has.

While the major powers may continue to maintain a token manned bomber force, the existence and potential of strategic nuclear missile forces make it appear unlikely that the manned bomber will be a major component in defence systems in the foreseeable future. The very high cost of a next generation of manned bombers is another strong deterrent to its development and production. Combat aircraft may therefore be required only for tactical air support in such roles as the provision of local air superiority, interdiction and strike, close air support, and air defence of all kinds. Presently, there is a great need for modernization of this particular class of aircraft. The North Atlantic Treaty Organization, for example, has no standard fighter and it is unlikely that this situation will change in the near term until new, Mach 2.0, air superiority fighters become available to replace the 1950-vintage types now in service. For the longer term, the most important consideration will be the already high and steadily increasing costs of combat aircraft. This makes it essential to achieve continuous improvements in cost / effectiveness, and the frontiers of technology will need to be pushed forward to achieve them—but not without further boosts in the upward cost spiral. The point may be reached where only the major powers can afford the most advanced combat aircraft and the smaller powers may have to set lower performance targets for their aircraft.

It is to be expected that recent advances in jet engine technology will provide combat aircraft power plants with much greater thrust and thrust / weight ratios and with improved fuel consumption characteristics. New materials for aircraft structures may promise some savings in weight, but these are likely to be offset by the additional weight required to provide the variable wing geometry made necessary by the very large speed range between the maximum and the desired landing speeds. There will be increasing use of vertical take-off and landing aircraft, such as the British *Harrier*, to free front-line aircraft from dependence on runways. Maximum speeds are not likely to exceed the Mach 2 to 2.5 range because of the many problems introduced by kinetic heating and because of the questionable military value of even higher speeds in this class of aircraft.

Progress is likely to be more rapid and dramatic in the case of aircraft equipment where the impact of micro-miniaturized, integrated electronics is only just beginning to be felt. There is the desire to exploit this feature in order to compress more and more complex automated functions into less and less space. Every advanced combat aircraft will perhaps contain a small, high-speed, high-capacity computer which will handle the functioning of the aircraft with the minimum of human involvement. The basic techniques of inertial navigation, doppler, airborne radar and other systems are well established. Present and anticipated future advances in electronics will permit the carrying of a multiplicity of systems and the integration of their functions, along with automated data handling and preprogramming of flight plans, fuel control, fire control for airborne weapon systems, surveillance and so on. Finally, although the techniques of communication are of long standing, modern advances should permit greater diversity in communication capabilities in any one aircraft.

The United States will most likely continue to dominate the combat aircraft field because of its established and advancing technologies. It will be difficult for any one European country to challenge this lead from the point of view of its diversity, economic strength and dynamic design capability. Multinational development programs offer one approach, but they have inherent disadvantages as well as advantages. The in-

creased use of multirole combat aircraft offers another alternative, but here again it is questionable whether or not the advantages of such projects outweigh the danger that the ability to perform will be compromised in such a way that none of the roles will be performed well. A final possibility could entail a re-examination of the basic concept of combat air operations. With so much automation of functions, the human operator is becoming more and more redundant and could be left on the ground—except that recent space flights have demonstrated the value of human judgement in the most complex of situations. On the other hand, there might be a great deal of merit in moving some of the automated functions back onto the ground, leaving the pilot to impose his judgement on the operation and control of the aircraft. This could permit some reduction in size and complexity. A trend back to lower cost aircraft with greater human involvement may be feasible in some situations, but it could be disadvantageous in a strongly competitive one in which a more technically sophisticated enemy is being faced.

The present military transport aircraft, like their tactical counterparts, are largely obsolescent and will have to be replaced in the near future. Much of the foregoing discussion is relevant to them, but there are some important differences. This type of aircraft is less radical, since it is less complex, and is developed to meet specific requirements of its own from the same current technology that is applied predominantly to the design of civil transports. Short take-off and landing characteristics are likely to grow in importance and desirability, but for vertical take-off and landing operations the helicopter is not likely to be challenged by any other type in the foreseeable future, since it is the most efficient military aircraft in that role. Armed helicopters with reduced vulnerability are most likely to survive in the battlefield, and further improvements can be expected in this regard. The costs of transport aircraft are not increasing as rapidly as those of combat aircraft. The demand for this type will increase considerably.

For surveillance, reconnaissance and early warning aircraft, the airborne electronic equipment is likely to cost as much or more than the aircraft themselves. New aircraft of these types should not need radical new design features, but they will carry large quanti-

ties of the most advanced sensors and avionics—representative of a rapidly developing technology which is likely to revolutionize our ability to acquire, analyse and process large amounts of data. Use of such aircraft can be expected to increase considerably.

Domination of the support aircraft field by the United States is less inevitable than for combat aircraft. Development costs are within the resources of a number of countries, especially when there is a related civil requirement. Competition will therefore be stronger. While the United States has a commanding lead in most of the relevant technologies and can justify the development costs on her own needs, Europe should not be ignored as a possible source of new aircraft. Nevertheless, there are in the United States highly capable managements and efficient production facilities as well as continuing logistic support after sales. Government support will undoubtedly continue to be a significant factor in the development and production of military aircraft in all countries in which they are produced.

Civil

It has been conservatively predicted by a number of authorities that in the next decade there will be $2\frac{1}{2}$ to 3 times as many passenger-miles flown and $2\frac{1}{2}$ to 3 times as many people using air transportation as there are today. In 1968 the world's airlines carried 5.44 billion ton-miles of air freight (19 per cent above that of 1967). It has been predicted that there will be 8 to 10 times as many ton-miles of cargo flown 10 years from now, and further very rapid growth thereafter. General aviation, representing all civilian operations other than the air-carriers, is expected at least to double—as measured by the number of aircraft employed—in the next decade. This expansion of commercial and general aviation will reflect an immense growth in the worldwide market for new aircraft. Competition will remain strong, and innovation will be a key factor for success.

Commercial aircraft will be continually improving from an operating cost point of view. Some of the improvements which it is hoped to achieve in the next 10 years are:

- turbine engine thrust/weight ratios will be 40 per cent higher;
- the permissible operating temperature of turbine material will be 20 per cent higher, giving higher power output;

- the specific fuel consumption of turbine engines will be reduced by 20 per cent;
- the aerodynamic efficiency of commercial aircraft will be 40 per cent higher;
- air transport aircraft will be able to perform 3 to 4 times as many ton-miles in a day because of increased size and speed, but their capital costs will not increase proportionately; and

- airline fares will decrease 25 per cent in dollar value, with better service given to the customer.

If substantial R & D in the supersonic transport field is continued, it has been predicted that in 10 years time it should be possible to design a supersonic transport that could be economically competitive with subsonic transports. Current supersonic transport designs are not competitive, with the *Concorde* estimated to have a direct operating cost at least 60 per cent higher than the current subsonic jets, and indicating the need for a surcharge. Meanwhile, subsonic commercial aircraft will benefit from current research leading to the "supercritical" aircraft which, through subtle design changes in wings, wing roots and fuselages, will be able to fly closer to Mach 1.0 with no appreciable increase in power.

The Boeing 747 will handle the very high density long-range services well into the 1980s. The wide-body (two aisle) twin-engined descendants of the Lockheed 1011, Douglas DC-10 and German-French A-300B (air bus) will most likely dominate the air travel market of the major airlines in 10 years time, replacing the 747 on the lower density traffic services.

In 10 years time, STOL-type aircraft will have begun to dominate the short-haul air services up to 500 miles and will have made some inroads into the surface travel market. Even a 1 per cent penetration would yield a tremendous expansion in air transportation. It is unlikely that VTOL aircraft will be economically viable for scheduled services within 10 years, but may be able to take over from STOL aircraft by the end of a second decade.

Assuming that the standard of living in North America and the other prosperous regions of the world continues to increase, the demand for air travel should also increase—but it may be hampered to some extent by the lack of planning and capital to provide adequate airport facilities and air traffic control systems. It is essential that a broad approach must be taken with regard

to every aspect of air transportation if the maximum benefit is to be realized from each new technical advance. Present congestions at airports could be reduced, for example, if the short-haul traffic (up to 500 miles), which now involves more than half of all the airline passengers, could be assigned to STOL aircraft operating from a number of small interurban airports. It is evident that the pressure is there for air transportation to absorb gradually a larger and larger share of the total transportation market. To achieve this, technological developments that permit more economical operations over distances below 500 miles will have to be encouraged. For longer ranges, the sophisticated airliners of ever-increasing size will continue to dominate the market. The rising costs of large transport aircraft will have political implications in that government backing and financial support will be essential for these high-risk development projects. So much capital is even now tied up in the design, development and production of new commercial aircraft before they can be delivered and placed in revenue-producing service that most of the large manufacturers have been facing financial difficulties.

The nuclear-powered aircraft continues to receive attention. A recent NASA study has concluded that with a gross weight of 1 to 2 million pounds, such a transport aircraft could carry a payload of 15 to 25 per cent of its gross weight at a speed of $M=0.8$. Because of low fuel costs (reactor life would be 10 000 hours) total savings over the life of a 1.75 million pound aircraft could be \$40 million. Constant improvement of jet engine economics indicates that the nuclear-powered aircraft will have difficulty gaining acceptance. The situation would be different if it could be shown that this type of aircraft uniquely meets an important requirement. This could be conceivable by the 1980s, but not before, and will be dependent on the ability to ensure complete safety against contamination in the event of a crash in a populated area.

The immediate future will see the giant Boeing 747 entering service, followed by the air buses—the Douglas DC-10s and Lockheed 1011s. The *Concordes* should also be entering service in several years time and we shall discover just how severe will be their sonic booms and how tolerant the public will be of them. In this connection, however, it is accepted that aircraft noise must be reduced

and extensive research is now in hand to help bring this about. Perhaps the sensitivity of this subject of noise is delaying the introduction of v/stol operations from downtown airports. City governments may be loath to bring the commercial aircraft to the very core of the cities at this time. Yet the need to introduce such services as soon as possible is receiving increasing attention and acceptance. Although there may be some economic penalties in silencing existing aircraft types, there is less possibility of substantial handicap if low noise level is a factor in initial design.

There will be growing pressure on the airlines to achieve low visibility landings on a routine basis so as to remove a major obstacle to the regularity of the so-called "scheduled" air transportation flights. The problems in this area are not so much technical in nature as physiological, and the ultimate design of suitable systems will require the solution of a number of problems faced by airline pilots when coping with low visibility conditions.

The present air traffic control system has not kept pace with the growth of air traffic and changes are imminent to bring it up-to-date. The introduction of inertial navigation to commercial aviation holds the promise of ultimately reducing traffic separation requirements on long-range routes without sacrificing safety. New techniques of area navigation will permit a wider separation of traffic on domestic routes by a better utilization of the existing air space. Equipment will be available in the near future to provide this capability on airliners. This will greatly improve the *en route* control of traffic and will effect a speedier and safer routing of it through the approach and departure zones at airports. The adoption of modern electronic advances in the equipment in air traffic control centres and control towers will enable automation to be increased and the workload on controllers reduced.

In the United States there are no doubts about the continuing importance and dynamic nature of military aviation. At the same time the tremendous growth in size and importance of civil aviation has brought it to a position of pre-eminence. As a consequence it has become a subject for intensive study with a view to determining policies which might govern the participation of the federal government. The first such study was undertaken by the Aeronautics and Space En-

gineering Board (ASEB) of the National Academy of Engineering (1967-68) and covered the subject, *An Assessment of Federal Government Involvement in Civil Aviation Research and Development*. This study, carried out in consultation with U.S. government agencies and private groups, concluded that civil aviation can continue to flourish, with accelerated beneficial growth, if a carefully conceived program of planning and research and development aimed specifically at the civil air transport system is carried out. The Board concluded that the three most critical factors affecting this growth are airport and support facilities, noise, and air traffic control.

President Nixon's administration has drawn up a timetable for the establishment of a long-range program for civil aeronautics research and development with an initial blueprint in October 1969 and the final report to the President in January 1971. This will be submitted jointly by the Secretary of Transportation and the Administrator of NASA. The policy study group's executive director Lawrence P. Greene is charged with providing the two agencies with immediate assistance in developing their programs of aeronautical research and development, by contributing to the classification and identification of aviation-oriented R & D programs for the fiscal 1971 budget. This impetus for the establishment of a U.S. national program for civil aviation R & D has come from the House and Senate Space Committees.

In the same way that the U.S. space program has been built very largely on the technologies developed to meet the needs of aeronautics, it is to be expected that these technologies will continue to be utilized to an increasing extent for non-aeronautical applications.

Chapter VIII

Aviation in Canada in the Future

Military

The future of military aviation in Canada will be determined by the defence policy which is currently under critical review by the government. The broad outline of a new policy has been announced but the detailed military missions and force structure have yet to be established. The new policy differs from the old in increasing the priorities attached to the preservation of sovereignty and territorial integrity and to North American defence. It will also be concerned with reducing the priorities attached to participation in the NATO alliance in Europe and to United Nations peacekeeping operations. A primary consideration is to be the attempt to provide a force having equipment which is not aimed primarily at the European commitment but to utilize the force, organized for other purposes, to meet a need in Europe. Superimposed on these considerations is a significant reduction in the total force level and a constant budget for several years to come, making it unlikely that the level of expenditure on military aircraft will increase significantly above the level of the past few years. The increasing cost of aircraft, coupled with the substantial number approaching the end of their useful life, implies a reduction in the total number of aircraft which will be operated by the Canadian Forces.

While the full implications of the new defence policy cannot be assessed in this present report, it is possible to foresee a number of emerging and relevant trends. It is probable that the nuclear strike role performed by CF-104 aircraft in Europe will not be continued with new aircraft. On the other hand, there is likely to be increased emphasis placed on the reconnaissance role, so that an *Argus* replacement will be required, and it will probably need to be equipped to operate in the North as well as continuing in the air-sea warfare role. A replacement for the CF-101 would be required for continued Canadian participation in NORAD or, alternatively, participation could take other forms such as in the AWACS (airborne warning and control system) role. The importance of high mobility and remote area operation could add emphasis to transport aircraft of all types including short-range tactical transport by small helicopters. Short take-off and landing aircraft will be needed for short and medium ranges. It is to be expected that some combat aircraft

will be required to support the ground forces, but it is not possible at this time to define the roles they would perform.

It is deemed desirable to reduce the multiplicity of aircraft types in the Canadian Forces' inventory, but this is unlikely because of the diversity of roles the Forces are expected to play. The result will be a reduction in the number of any one type of aircraft to be acquired. It is therefore difficult to see any circumstances which would justify the development of a complete aircraft system in Canada to meet the needs of the Canadian Forces alone. Hence, most military requirements are likely to be met by aircraft developed elsewhere and either purchased directly or built under licence in Canada. This latter alternative might be more costly but it could strengthen the Canadian aircraft industry, especially if it could be linked to opportunities for exports.

Any involvement by the Canadian Forces in a complete aircraft development project must take into account political, economic and industrial factors besides defence needs. For instance, development of an aircraft to meet Canadian Forces' needs might be justified if there were a good sales potential for the product and if the industry had developed a new concept representing a significant technical advance over the available systems. There are, however, severe limitations to this approach. It is believed that the development of a combat aircraft costing several hundred million dollars cannot be contemplated. Not only would this be economically impossible, but neither the breadth nor depth of technical skills is now available to support such a program. Also, the supporting resources within the Canadian Forces to provide the design authority function and to perform the required test and evaluation are unlikely to be available. Any development which is contemplated should, therefore, be limited to the smaller and less complex support type of aircraft. It should be recognized, also, that the strong desire to standardize military aircraft with our allies to achieve operational compatibility and logistical economy does not favour the acquisition of a uniquely Canadian aircraft.

This situation still leaves a dilemma. On the one hand, it is surely desirable to have available in Canada an industrial capability in the military aviation field. This is necessary to produce aircraft incorporating adaptations to meet unique Canadian needs, to under-

take product improvement, and to provide the basis for the essential maintenance and repair functions. Also, involvement in the military aircraft field provides important access to a broad range of the most advanced technologies which may have important civil applications. On the other hand, however, the premium which the Canadian Forces can afford to pay to support the industrial base is apparently very limited. But there is a possibility that in the long term this situation could improve. The rapid growth of Canadian industrialization suggests that a segment of the airframe industry may prosper sufficiently by civil aircraft production and development to be capable of diverting a portion of its facilities towards military aeronautical support. This situation could be helped if an opportunity should arise for Canadian participation in a multinational military aircraft development project which includes the necessary favourable economic circumstances and a clearly defined Canadian military requirement for the aircraft itself if the project is successful.

There seems to be no way in which it will be possible to develop large, advanced power plants in Canada for military purposes in competition with the few major manufacturers abroad unless conditions change radically. The development of smaller power plants in this country will most likely continue but, again, development and subsequent production are unlikely to be geared primarily to specific Canadian military requirements.

There is, however, considerable scope for the development in Canada of subsystems, accessories and components. Projects will be most attractive if they can be based on a Canadian military need, a demonstrated industrial capability and a novel concept in advance of the state of the art which is likely to provide export potential in addition. Great care and good judgement are necessary in selecting projects, which must then be pursued with courage and enthusiasm if success is to follow.

Civil

In the decade of the 1970s, Canadian civil aviation is expected to reflect the character and growth trends of civil aviation in the United States, as in the past, rather than those of world aviation. Canada's proximity to the United States and the pace-making

activities in aviation in that country are the major factors in this judgement*. It seems safe to say that aircraft of all kinds will be used more often by more Canadians in the future and that with regard to numbers of aircraft, the general aviation sector will grow faster than the main or regional airlines.

The following growth trends for civil aviation in Canada have been based on a recent Department of Transport forecast, *Canadian General Aviation 1967-1980*:

- the total fleet of aircraft on the register will increase by about 90 per cent to a level of 17 500 aircraft in 1980 and all but approximately 270 aircraft, which will be used exclusively on scheduled services, will be in the general aviation category embracing private and state-owned aircraft and non-scheduled carriers;

- the hours flown by these aircraft will increase to about 4½ million by 1980—of which the scheduled and non-scheduled carriers' (commercial) share will represent more than twice its present level and the shares of both private and state-owned aircraft will rise by about 75 per cent over present levels;

- the scheduled carriers should—with only 270 aircraft—account for at least 20 per cent of the total of 4½ million flying hours;

- commercial flying as a whole should account for three quarters of all civil flying, and private and state flying for the remaining quarter.

These trends are on the conservative side when compared with simple extrapolations from the existing growth curves. The Department of Transport has explained, however, that various economic indicator forecasts were taken into account in the performance of its own forecasting exercises.

Special mention must also be made of the air cargo business in Canada which has trebled during the past eight years. This business is expected to continue to expand significantly in the years ahead but a satisfactory technique for forecasting future levels has not yet been developed. One important reason for this is that the impact of air transport on freight movements is only now beginning to emerge. These movements are

*It might be argued that the Russian and Anglo-French supersonic transport aircraft are leading the U.S. efforts in this particular field. However, as far as the decade of the seventies is concerned, it is still not clear just how extensive the use of supersonic transports will be in the civil aviation marketplace.

likely to receive substantial boosts over the next few years from the introduction of the "jumbo" or wide-bodied aircraft and from improvements in the provision of freight terminals and facilities which are now under-way or are in the planning stages in a number of countries.

It will be essential for the scheduled carriers, and for all other aircraft operators in this country, that technical competence and support facilities should be developed to assist with the solution of problems associated with the operation of aircraft specifically in the Canadian environment. The operators themselves must either possess such skills or have access to them in order, for example, to plan safe and reliable operational schedules, to investigate instances of mechanical and electrical failure in service, and to develop improved training, test and safety techniques.

It is reasonable to assume that this competence should be backed up by manufacturing capability involving the production of aircraft subassemblies, components and instrumentation, and in some cases the production of complete aircraft. As discussed in the opening remarks of Chapter IV, the aircraft industry has, in recent years, exploited an export market which has been largely of a military nature. A major concern is whether or not this industry can survive in the future on the basis of increasing attention to civil requirements in the face of a likely continuing decline in the domestic military market and possible adverse change in the overall export market.

This manufacturing capability must also be supported by aeronautical research facilities. Much of the new knowledge will have to be "imported" from abroad in one form or another but it cannot be used effectively unless the research, engineering and operations people in Canada have background experience of the subject matter adequate for their respective needs. The supersonic transport is a case in point. The only entry Canada has to the current supersonic transport developments is through the reserved purchase rights of the two principal carriers. Canada has had no part whatsoever in the initial development of this major new type of civil aircraft or even of its military forerunners. The major scheduled carriers in Canada are expected to continue to operate foreign aircraft in the foreseeable future, since it is unlikely that a Canadian company

will be able to enter the manufacturing market for complete, large, long-range aircraft to meet this requirement.

While the importance of the competence and support facilities discussed above has been generally recognized in the past, the greater numbers of aircraft of all types which are expected to be flying in Canadian airspace by the end of another decade and the possibility of a strong demand for many more aircraft to work in the northern and Arctic environments lend emphasis to the changing dimensions of this need. Also, as aircraft in the general aviation category make use of more small turbine engine developments, electronic advances, computer applications, and the new composite materials, the effectiveness of maintenance, repair and overhaul companies will be impaired unless the personnel involved acquire new levels of knowledge and experience. New equipment will be required, and this could be a larger problem still which may need to be solved through the establishment of specialist laboratory and test facilities at the main centres of aviation activity throughout the country.

The support of aircraft themselves and of their operations are only two of the elements in the field of civil aviation in Canada which should be considered as serving the economic and social needs and opportunities of the country. If civil aviation is to survive and to grow in step with economic and social growth, then some of the research and development resources and objectives must be related to elements in the field such as noise and air pollution and to the cost of bringing these elements under control. There will also be a requirement for R & D programs, perhaps especially those of the National Research Council and the Department of Transport, to be extended appropriately in areas such as supersonic transport operations, short-haul-urban centre-to-centre operations, air traffic control, and the ground transportation environment associated with scheduled carrier operations. The needs of Canadian civil aviation operations should lead to a closer working arrangement between the operators, the laboratories, and the manufacturing and service industries than presently exists on a limited basis between the operators and the support shops and between the laboratories and the manufacturers.

Another specific aspect of the future of civil aviation in Canada should be mentioned, namely, accident trends. On a "rate" basis,

current Canadian accident statistics appear to be "tolerable" but with future increases in the numbers of aircraft flying and in the numbers of passengers which some of these aircraft will carry, even a continuation of this current low rate will mean many more accidents and deaths. The concerns expressed on this point will need to be relieved through in-depth studies of the causal factors in past and potential future accidents and through appropriate research programs launched to find means of reducing the hazards involved in flying. Thereafter, suitable aircrew and ground-crew training programs will have to be developed.

Some of the investigative work which will be required in support of future civil aviation activities in this country could be done in the universities. Such work might also influence the aeronautical content of university courses and subjects such as flight safety and aviation legislation could be taught as subjects in their own right. The ultimate ability of Canadians to maintain a pool of scientific and technical knowledge in aeronautics will depend to an important degree upon the ability of some of the universities in this country to train people and to participate in the solution of research and development problems. Importing new knowledge, important as this will continue to be, will not be enough. Information originating abroad cannot be—and is not—always shared freely with others, including individuals and companies in this country. At the same time, of course, the most vigorous possible efforts must be maintained to maximize access to, and effective use of, information from abroad.

It is believed that the future of civil aviation in Canada will be linked with developments abroad and a few of the linkages have already been touched upon. Others, such as Canadian duties and commitments, under international agreements and under bilateral or multilateral agreements with other countries, have importance politically and economically and may affect the operational side of aviation, and the manufacturing and service sides, including research and development. The manufacturing side, in particular, is also sensitive to the opportunities which foreign companies have to sell their products in this country and to the opportunities for the export of Canadian products. As has been mentioned earlier, there are likely to be about 17 500 aircraft on the Canadian register by 1980. The corresponding figure for the

United States, however, may be of the order of 250 000—up from about 110 000 at the present time. There would therefore appear to be opportunities for Canadian manufacturers to satisfy certain special needs within the North American market as a whole, with further possibilities in the rest of the world. There are in Canada companies which could take advantage of these opportunities.

The Canadian industry has, for example, demonstrated a capability to become one of the leaders in the STOL aircraft field. To achieve and consolidate such a position requires that there should be strong and prompt support and encouragement from government for advanced aerodynamic and other concepts, generated by industry, which promise to accelerate the arrival of the true STOL aircraft. Here again, Canada should exploit the gaps in the market so that our industry does not find itself in direct competition with the major U.S. aircraft design companies. The general aviation field, which is rapidly expanding, is one which Canadian industry, with its experience garnered from STOL-type aircraft design, should continue to explore for opportunities in domestic and foreign markets.

As regards large military aircraft and modern airline types, the trend in the United States is for the big manufacturer to become a "basic airplane" designer only, a co-ordinator of detail design, and an assembler of components manufactured elsewhere. This trend provides an excellent opportunity for the Canadian industry to participate as a subcontractor to design and produce the components for which they feel best qualified. Such participation must be encouraged, both for the jobs that are provided and for the opportunities afforded the companies concerned to improve their overall competence. The stability of such business will depend largely on the performance of the Canadian industry, which will be based on its ability to create good quality, integrated engineering teams and especially to refine its production methods and capabilities. The conduct of effective R & D, not overlooking R & D in manufacturing techniques, will be important in enabling Canadian industry to capture and retain a lead in this very competitive business. The opportunities for research and development activities are initially negligible, but they usually increase with time, competence and experience from work

on manufacturing techniques, through the redesign of the components themselves, and eventually towards the design of complete aircraft. Co-operative and consortium agreements at the intercompany or intergovernmental levels must therefore be encouraged where clear long-term advantages to Canada can be foreseen—particularly where the Canadian authorities are strong enough to influence negotiations so that Canadian research and development *as well as* manufacturing activities are included in the agreements. The design and production of such accessories as aircraft landing gears, hydraulic systems, fuel control systems, self-sealing fuel tanks, and aircraft instruments could well extend into the worldwide market. By pursuing and capturing such opportunities the Canadian aircraft industry can continue to add to the economic growth of this country.

In the case of aero-engines Canada appears to be well on the way to leadership of the low-powered turbine engine field. It should be possible to strengthen our position, and to maintain it, with continuing R & D in Canada undertaken independently from the associated U.S. industry whose R & D efforts are concerned with large and sophisticated engines. Fortunately, there is a large overlap in being able to use R & D results to some extent both ways, for large and small power plants. Canadian industry will without doubt apply effort to refine the engines already under development, to enhance their acceptability in a changing market. The personal and small utility aircraft market is presently not being served by gas turbines and it offers a large potential for a low-cost engine.

The industrial turbine market continues to expand, with Canadian industry filling a significant place. Refinement of current products and the introduction of new technology based on increased R & D activity will enhance the penetration of this market by Canadian industry.

In avionics the significant developments include the undertaking by Litton Systems (Canada) Limited of the exclusive world production of the LTN-51 inertial navigation system for commercial aviation, the development of flight simulators for the latest commercial aircraft by CAE Industries Limited, the manufacture of air and ground-based communication systems by several Canadian companies and the development of tactical display systems. In the next decade there

could well be an expansion of Canadian industrial competence in this field based on an existing diversity of products coupled with some rationalization of the industry and reduction of its fragmentation by mergers or acquisitions. It is imperative that we sustain this growing Canadian capability to design, develop, manufacture and sell internationally a wide variety of avionic and accessory equipment for aircraft, and electronic and other equipment for ground-based aviation installations.

As mentioned briefly in Chapter VII, aeronautical technology will be increasingly employed in non-aeronautical applications. Obvious examples in Canada are hovercraft, high-speed trains and marine and industrial power plants. Less well known perhaps is the new field of architectural aerodynamics, as exploited in the preliminary design of the new City Hall, Toronto, in the study of the influence of wind flow, in combination with rain, on the design of windows for tall buildings and the forecasting of wind loads on roofs of large buildings. The techniques of aircraft structural analysis and aeroelasticity are finding increasing industrial applications, a typical case being that of bridge design. The value of the aerospace systems approach to managerial problems at the industrial and national levels is recognized and will no doubt be extended to cope with urban and other social problems. Finally, an aeronautical technology some 30 years old—simulation training—is just beginning to find wider use and no doubt its applications will expand as its merits are more widely appreciated.

The Government of Canada has owned and operated the major aeronautical research facilities in this country in the past and will continue to do so because the industry has neither the resources nor the desire to take over these functions. The government has also supported university research in aeronautics. However, in the past, the aeronautical research programs in government and university laboratories have not always been relevant to the needs of the aviation industry, although the industry itself has not always made its requirements known in an appropriate way and at the appropriate time. But the strength of government support for aeronautical research and development in Canada will not all stem from financial contributions or from the ownership of facilities. Part of this strength has to come from the ideas, encouragement and co-operation trans-

mitted and engendered in the public sector by those government departments and agencies associated with aviation.

There are a great many problems which require attention but not necessarily extensive research or development. In some cases, the difficulties lie more in the transfer of the technology and education than in the development of new technology. Among these problems are cockpit displays and standardization; airport location and zoning; fire-fighting and rescue; the development of a small, inexpensive crash position indicator; the drift of chemicals from airborne spraying operations; approach accidents and incidents; accident investigation and prevention; collision avoidance; and airworthiness certification for new types of aircraft.

There is a whole range of compelling reasons for the Government of Canada to remain active in its support of aeronautical research and development activities in Canada and to increase this support. Indeed, the acceptance of only a handful of the defence, economic, technical, sociological and other points made in this and the next two chapters should suffice to stimulate action in this direction. Perhaps the most important point of all is that Canadian needs and problems in aviation should be satisfied and solved—if it is at all possible—in Canada with the help of people and companies in this country.

Chapter IX

Guidelines for Future Canadian Aeronautical R & D Activities

This chapter will seek to identify factors and motivations which are relevant to the planning and implementation of both current and new aeronautical research and development activities, as they relate to the future of aviation in Canada discussed in the preceding chapter, and will suggest certain guidelines upon which the forward-looking conclusions of this report may be based.

The environment in which Canadian aeronautical research and development endeavours must now be made is quite different from the environment of 60 years ago. Among other things, the success of Canadian secondary manufacturing industries in regional, national and international markets is much more closely linked to technological advances than it used to be. Defence and national problems have become more complex and the hardware and skills required to solve them have become more sophisticated—and usually more costly. An effective transportation system has always been an essential element in the continuing development of this country, but the role of aircraft in this system has now become of enormous importance.

This new environment has also placed increasing emphasis on the innovative process and its relationship to economic growth. To remain competitive in both domestic and foreign markets, the various industrial sectors of a nation must continually innovate. This generally requires scientific and technical knowledge which may be obtained from two sources—the existing pool of world technology (including Canadian) and new knowledge developed through R & D activities within the country involved.

The process of tapping the existing pool of world technology for innovative purposes is frequently referred to as “technology transfer”. From industry’s point of view, the objective of this process, or of home-grown R & D, is the output, *on an economically viable basis*, of new or improved goods and services which can be readily marketed. This purpose can only be accomplished, however, when management moves from the technology transfer or from the R & D stage into detail design and product engineering, followed by production and marketing. It is this latter exploitation of technology, research and development which really comprises innovation.

At the level of the individual company, the technical underpinning for innovation may owe much more to the efforts of outside

researchers and institutions or to straight imitation of an existing product than to the work of the company’s own scientists and engineers. This kind of situation is quite common. Only a small portion of any company’s requirements for new scientific and technical knowledge can normally be generated within the company—and the same applies at the national level in most countries. An innovating company has to have foresight and the resources necessary to manufacture, to sell, and to service its new product. It must also have the wit and technical competence to understand and make use of “outside” information and to fill any gaps by using its internal resources. The existence of R & D capabilities within a company often facilitates access to outside information. It also confers the ability for effective appraisal of the relevance of such information. Also, companies which do R & D often find that they can sell or exchange the results of this work under a licensing or “know-how” agreement.

Demand for new products or services based on innovation may not only be closely associated with economic growth, but may also contribute to rising employment, improved productivity, higher incomes of consumers, business organizations and governments, expanded exports, and increased investment in productive resources (including R & D, & I). Strong economic growth is, in turn, a vitally important means for improved satisfaction of human and social objectives. A large part of our industrial R & D and technology transfer activities should therefore be oriented towards innovations having the greatest potential economic and social pay-offs within the framework of national goals and objectives.

Apart from generating economically viable innovative activity, there are two additional motivations for performing R & D and for encouraging the transfer of technology. The first may be referred to as a technological objective in that it adds to national scientific knowledge and the long-range potential for innovative exploitation but provides no assurance of short-range innovation. Such activities act as “listening posts” for advances in science elsewhere in the world enabling a country to engage in the international import-export trade in technology; they are also of educational and cultural value in that they support the research and development people and their ideas.

The other motivating force behind these technical and innovation activities falls under what might be termed "national interest considerations"—for example, broad political, defence, prestige, and international relations goals. The activities may or may not have economic, social or technological advantages in addition.

There are, then, three logical reasons which, separately or in combination, govern the acceptability of technology transfer or R & D activities (in our case aeronautical R & D):

1. They should lead to commercially viable innovation, contributing to economic and social gains in Canada.

2. They should add to the pool of scientific knowledge, with potential for possible future innovation.

3. They should lead to innovation which is justified primarily on national interest grounds.

It now becomes possible to consider the principles which should guide the endorsement of aeronautical R & D programs falling under these three categories. In the case of the first category the object is innovation and economic and social gains. Because the total Canadian demand for new civil or military aeronautical products is strictly limited, the R & D programs can seldom be justified, economically, on domestic requirements alone and must therefore be supported on the basis of export potential also. There will be cases, of course, where the domestic market alone may justify an R & D program on the basis of a reasonably long production run, more than adequate to achieve a break-even point within a reasonable time period, and on the basis that the total R & D resources required by the participants will be of acceptable and manageable proportions.

Since aeronautical R & D programs are, by nature, usually long-term projects, participants must be prepared to follow through to success, subject to acceptable progress and the market remaining a genuine one. It is also an important principle that the R & D program should exploit and also add to Canadian aeronautical resources and expertise and be consistent with the Canadian aerospace industry's long-range plans for technology and product specialization.

If these principles are not violated, then rough guidelines can be formulated to assist in the selection of R & D programs that will contribute to economic growth. Where a need for an aeronautical product is respon-

sive to the Canadian environment or to a Canadian government policy, and the domestic market alone or in concert with the export market is expected to justify the R & D program, it should be acceptable. A program should be acceptable also if the domestic demand for the product, in concert with that of one or more other nations, would spark a bi- or multi-national co-operative program from which an economically viable joint production program is anticipated. Again, if Canada achieved a technological "break-through" enabling the ensuing product to capture a lead position in the international competitive queue or to fill a gap between similar leading products, then an R & D program should be acceptable as commercially viable even in the absence of an initial domestic demand.

Turning now to the second category, where the objective is to augment national scientific knowledge, certain principles can be enunciated. First, an advanced industrial nation has to keep abreast of world technology in order to respond to economic and social situations that are influenced by technology (e.g. to make sound decisions in the purchase of foreign designed military or civil aircraft and to be able to operate and maintain such aircraft in our environment). Second, it enables us to participate in the international trading of technology, a two-way traffic wherein we generate exportable technology and are competent to exploit imported technology. Third, an inherent feature of an advanced industrial economy is the climate for encouraging bright people to generate new ideas and knowledge. This may justify certain R & D programs in the absence of foreseeable economic gain, particularly in fields of national importance (e.g. transportation). Fourth, manufacturing industry's involvement with development can improve the technical and economic feasibility of current and subsequent production cycles. Finally, as before, the R & D programs should both exploit and add to Canadian resources and expertise and be compatible with our industrial long-range plans for technology and product specialization.

Based on these principles, rough guidelines again emerge which should be useful in selecting R & D programs beneficial for technological gain. Acceptable R & D programs would permit Canada to keep abreast of aeronautical technologies deemed to be relevant to our civil and military aircraft, equip-

ment and operational needs. The R & D programs might or might not be commercially profitable. Another class of acceptable programs would be one that enables Canada to participate, as appropriate, in certain international arrangements for the exchange, or joint development, of aeronautical technology. Again, R & D activity contributing to the solution of difficult problems arising in aircraft operations in the Canadian environment is most important, even if not demonstrably profitable. Finally, R & D programs which lead to positive influence on the technological or economic viability of the production phase of an aeronautical product may be justifiable.

Coming now to the third category of aeronautical R & D, leading to innovation in the "national interest", here, the major principle arises from the national aim to provide all citizens with a just and secure society, with relatively equal opportunities and services for economic, social and cultural growth, and effective use of its human and other resources. This objective may require the expansion and use of technology, which may not demonstrate economic viability but does contribute to the long-term socio-economic development of the country, and is therefore in the national interest.

The guideline here, in selecting aeronautical R & D programs, is the degree of contribution to operational safety, national security, development of a "have not" region of the country, political necessity or similar need. Programs aimed at improved regulation and safety of civil aviation, preservation of national sovereignty by improvements in aeronautical equipment for Arctic use, "human engineering" research affecting aircraft crew or passenger well-being, etc., are examples of this class of acceptable R & D programs.

In conclusion, it should be emphasized that the principles and guidelines suggested in this chapter are not to be considered inviolate criteria, but rather a general framework to assist in the R & D decision-making process.

Chapter X

Possible Future Programs for Aeronautical R & D in Canada

It has been made clear in Science Council Report No. 4, *Towards a National Science Policy for Canada*, that expenditures on science and technology must compete with many alternatives in the allocation of national resources and that these expenditures will be selected because of social and economic benefits that will result. As was shown in the previous chapter, such benefits constitute one of the motivations upon which an effective program should be based.

The question of science policy as it relates to the aeronautical field has been considered in various briefs submitted to the Science Council Committee on Aeronautical Research and Development. The Technical Advisory Panel, representing government, industry and universities, pointed out that in considering Canadian aeronautical research and development policy, it must be recognized that Canada's need for air service is one of the greatest in the world. Indeed, to a very important degree, Canada's future development will depend on the air for transportation, exploration and national sovereignty. The Air Industries Association of Canada emphasized that our future economic health will be closely dependent on our ability to create, manufacture and sell new products; the aerospace industry is an advanced technology industry and operates in a competitive environment which makes continued research and development essential to survival.

In what follows, some principal program areas are suggested to which aeronautical research and development effort might be directed in Canada during the 1970s. Various mission-oriented and disciplinary fields of research to support such programs are also identified. It should not be assumed, however, that the Study Committee considers these to be the sum total of our important fields of research and development in aeronautics. They are discussed here as typical examples only of the kind of programs which should be considered. The principal program areas are analysed but no attempt has been made to subdivide the programs into a long list of individual projects or to assign detailed responsibility for each of them. Neither have the programs been justified on precisely defined grounds since the guidelines and principles which were applied to their selection have already been formulated in Chapter IX. Their selection was, however, influenced by some of the recommendations received by the Study Committee from, for example, the

Air Industries Association of Canada, the Technical Advisory Panel, and the Canadian Air Line Pilots Association, The Saskatchewan Flying Farmers, the Alberta Aviation Council and from companies and individuals with whom members of the Committee met.

1. v/STOL Aircraft as a Total System

In the densely populated industrial areas of the world the ground transportation systems have become saturated or are approaching saturation. The prospects for relieving the ground congestion are not clear and the costs are estimated to be prohibitive. Further, air transport for trips under 250 miles is hampered by the current generation of aircraft which require vast airport areas, and by the ground congestion which can cause portal to portal travel times of up to four hours. The development of integrated vertical take-off and landing (VTOL) systems promises to relieve the short-haul transport dilemma, but only when the noise control and the economics of VTOL aircraft have reached acceptable levels.

In the interim, the short take-off and landing (STOL) aircraft offers the opportunity for a degree of success in the short-haul problem until VTOL matures. However, even the STOL aircraft requires a systems approach to achieve success and it promises to offer systems solutions which will be compatible with the inevitable VTOL developments. These systems elements involve area navigation, special landing and approach procedures, passenger and cargo-handling facilities, fuel storage and handling, maintenance and repair, and airline and terminal management, in areas adjacent to or at the centre of metropolitan, urban and industrial focal points. It is highly likely that the evolution will see v/STOL* aircraft as an intermediate stage of development with emphasis initially on the STOL capability and a gradual introduction of the VTOL as the noise and economics permit. In fact, if the hover capability is not essential to vertical take-off and landing patterns, the pure VTOL development may not be essential to a portal to portal system, which could reduce the lead time to the short-haul concept.

*v/STOL in the opinion of the U.S. Federal Aviation Agency implies multi-engine turbine transport aircraft using power for lift, and (or) control, and (or) propulsion which are either capable or not capable of hovering over a fixed point in zero wind.

The important aspect is the need for the development of the total system.

The Canadian aerospace industry has established a leading position in the development of small transport and utility STOL and v/STOL aircraft. Experience has indicated that such aircraft generate sales for both commercial and military operation within Canada and in the export market. Further, the fact that Canadian industry cannot compete in the development of high-performance aircraft, suggests that if it is to maintain an independent capability to design, develop, manufacture, and sell internationally competitive aircraft, it must do so in the more modest end of the spectrum which embraces v/STOL developments. This approach could provide a much needed focal point for the Canadian aerospace industry.

The STOL vehicles can be adapted by the military, and have been to a degree, but civil successes have been restricted by lack of appropriate airworthiness criteria upon which to base national and international operational standards. A similar lack in navigation aids, approach aids, and STOL-port criteria has acted as a further impediment to STOL aircraft for which special airworthiness criteria might be created within national legislation. Therefore, if the non-vehicle elements of the system were given immediate attention, STOL aircraft could emerge in the near future to fulfill the interim short-haul needs, as well as providing an advanced base for v/STOL system requirements.

With regard to the v/STOL vehicle itself, a study of the total system soon shows that the mission cost/effectiveness dictates the nature of the powered lift, which may involve rotors, tilt wings, or various methods of direct lift and vectored thrust, and emphasizes where priority should be placed. Research, design and development in propulsive systems is a high-priority requirement for those missions which will achieve cost/effectiveness from direct lift or vectored thrust, and viable commercial transport aircraft appear to be in this category. Therefore, in using the systems approach to v/STOL development, the mission will be overriding, but not to the extent that there would be conflict between elements of different systems. Hence, STOL and v/STOL aircraft undergoing evaluation may be used to develop some of the system elements common to VTOL systems. A long-range program utilizing direct lift or vectored thrust could also be initiated as a total system.

Vehicle performance must not be compromised by overemphasis of a hovering capability, yet it must be adequate, and associated fuel consumption rates must be reasonable. Since a v/STOL aircraft is likely to be used extensively over heavily populated areas, power-plant reliability is important. Stability and control relevant to the special performance requirements of v/STOL vehicles and related low-level meteorological phenomena is an area for considerable investigation. Studies of low-level meteorological conditions, such as large-scale, ground-level turbulence, and their effects on take-off and landing are especially significant. Current designs involve noise levels that are socially unacceptable and both basic and applied research are needed on noise abatement. To maintain a prescribed flight path, considerable development is required in air traffic control, approach and landing aids, and precise navigation.

Recommendation of an active program of development of v/STOL aircraft in Canada is based partially on the existence of research capabilities which give this country a leading position. The 30-ft. wind tunnel at the National Aeronautical Establishment has been specifically designed for industrial development work under test conditions which easily compete with those in other countries. The National Aeronautical Establishment already has under development an airborne simulator capable of variable stability characteristics which can be used to investigate the flight behaviour of new v/STOL aircraft. Also, the Institute for Aerospace Studies has achieved international recognition of its competence in the fields of aerodynamic noise and low-level large-scale turbulence as it affects flight dynamics. Theoretical and experimental studies of jet noise and the development of turbulence-controlled tunnels as a new design concept, illustrate current relevant projects at the University of Toronto Institute for Aerospace Studies. Basic studies of jet sheets and other low-speed phenomena are also proceeding in the Department of Mechanical Engineering, McGill University.

The development of the total STOL and v/STOL systems in Canada involves risks and costs that must inevitably involve some form of government assistance. Success in such a venture will depend heavily on the degree of involvement and co-ordination of all interested organizations in industry, government

and universities. The establishment of a program of research and development in commercial STOL and V/STOL aircraft could bring into focus the efforts of all three sectors to accomplish a national objective capable of major contributions to Canada's technological progress, industrial competence, efficiency in transportation, and export capabilities.

2. Avionics, with Emphasis on Remote-Sensing Systems

Canada has clearly demonstrated a competitive technical ability in avionics as recent export sales have definitely shown. International markets for this kind of ancillary equipment are substantial, and evidently considerable support should be available to maintain the Canadian position in this field. In general, our objective should be to maintain an independent capability to design, develop, manufacture and sell specialized avionics and related aerospace ground equipment.

Remote-sensing avionic systems should be particularly important to Canada since their use is greatly facilitated by the availability of V/STOL aircraft and they show great potential as an aid in developing our natural resources. Forest management and control is a good example of the useful application of sensing instruments. Using radar, infrared, or laser-impulse scanning systems, information can be obtained on the total wood volume per acre, and on the topography and ground characteristics (e.g. rock, clay, muskeg, etc.), all of which are needed for regional planning. The detection of soil deficiencies by the observation of foliage, the monitoring of thermal radiation in designated forest areas and its relation to fire hazard, and the uncovering of insect and fungus infestations will facilitate appropriate remedies. The possible wide use of remote-sensing systems was indicated at a meeting in 1968 organized by the National Aeronautical Establishment at which representatives of ten government departments and two universities indicated a need for remote-operating instruments to detect budworm infection, crop disease, animal population, groundwater discharge, ice configuration, sulphur deposits, permafrost conditions, tree species, pollution in lakes and rivers, hot springs, volcanic activity and defective joints in power lines.*

The National Aeronautical Establishment is currently acquiring experience in the use of thermal infrared scanners, special cameras,

solarimeters, infrared radiation thermometers and high-sensitivity magnetometers. Instruments of this kind have been mounted in a *North Star* aircraft. In 1968 a survey of the Great Lakes was undertaken with the co-operation of the Department of Energy, Mines and Resources using the infrared scanners with considerable success. The mixing configurations in Lake Ontario at the mouth of the Niagara River and the discharge of thermal pollutants from power stations and sewage systems were clearly discernible. Future progress requires a study of the parameters governing the design of an instrument for a specified purpose, involvement of Canadian industry in the development and production of such instruments, and a Canadian survey capability when feasible techniques have been developed.

Canada already leads the way in magnetics. Remote-sensing techniques have received considerable attention in the United States, both in relation to aircraft and satellites. But because of the magnitude and unique nature of Canada's requirements, a special need for innovation is still apparent and areas of Canadian leadership are entirely possible. In particular, the data-handling problems in the employment of such systems provide a major challenge.

3. Small- and Medium-Thrust Engines

It has been amply demonstrated that the development of small engines for use on commercial and military aircraft as well as industrial and marine applications is well within Canadian technological and financial capabilities. Also, a world market for such engines can be secured from within Canada. It is notable that the engines of 78 per cent of all light, twin turboprop aircraft were designed and manufactured in Canada.

The success of such power plants as the PT-6 and JT15D engines is due to the greater simplicity of mechanical and aerodynamic design with minimum loss in performance. An intensification of the Canadian effort in this field of development to extend the range of data and analysis techniques could result in further simplification with improved efficiency and weight reduction. Power trans-

*Barringer Research Ltd., of Toronto, whose activities have not been mentioned elsewhere in this report, is the foremost Canadian company in the field of remote-sensing equipment.

mission systems particularly should receive more attention with a view to further simplification resulting in cost reduction and improved reliability. Methods should be developed to measure and predict the static and vibrational behaviour of rotating and stationary components. The development of composite materials for fans and turbine blades, and refractory materials and coatings for hot components deserve special attention, and research is desirable into effective, economical turbine cooling to facilitate high temperature operation.

The proposed emphasis on light-weight engines is consistent with the proposal for the total development of v/STOL aircraft in Canada since small turbine engines are required for shaft power and lift augmentation. In this particular application, power-plant reliability is of critical importance, and appropriate noise reduction must be achieved with minimum loss in efficiency.

Sales amounting to \$150 million were achieved in 1967-68, thus providing definite evidence that sizeable domestic and foreign markets exist for power plants in the small- and medium-thrust range. There is a clear need for active research and development in all aspects of small engine design in order to reduce capital and operating costs and ensure maximum reliability with minimum noise. It is concluded that the existing program of research, design, development, manufacture and sale of small- and medium-thrust engines could be enlarged and accelerated as a major Canadian objective in aeronautics.

4. Flight Safety and Reliability

Rapid developments in aeronautical science must be accomplished by a constant vigilance to ensure proper standards of flight safety. Each new aircraft introduced into service brings its own problems in reliability. Many difficulties are removed in the prototype stage but others appear later during operational use. More and more the public demand is for safe manufactured products and the right to adequate compensation when accidents occur. Consumer damage suits have forced industry to introduce reliability checks and government has recognized its responsibility to reduce public risk.

Improvements in aircraft safety and reliability begin with engineering research, design and development. Safeguards and fail-safe

features such as the duplication of critical components and the use of warning devices must be designed into the system. The operational environment must be better understood, materials variabilities must be reduced and analytical methods made more accurate. Careful consideration must be given to protective devices that will reduce loss and injury. Special problem areas must be emphasized in future research programs; for example even more emphasis must be placed on investigations of structural fatigue, and recently initiated studies of damage to aircraft due to bird strikes must be encouraged. Fatigue problems increase with the age of aircraft and they are a factor in any decision to retire an aeroplane from service. To date, bird strikes have not resulted in loss of life in Canada but financial losses to Air Canada and the Canadian Armed Forces have been considerable.

The intensive use of flight trials to check out a new aircraft under all conditions is economically impossible and exposes the crew to unnecessary danger. Recourse must be made to simulators. At present, ground simulators are designed primarily to train the flight crew and little provision is made to assess the flying qualities of the vehicle or to test for emergency conditions. Highly sophisticated ground simulators are needed to meet the latter requirements. To obtain a more effective simulation, it is advisable to develop an airborne simulator system which would permit a realistic study of the performance characteristics of different sizes of aircraft.

A significant modern development is the multichannel monitoring of every aspect of flight performance during actual operation. New aircraft are equipped with flight data recorders for this purpose. Ground systems are available to process the data and provide information on marginal performance characteristics and fault identification. Canadian industry is already involved in the development and production of both airborne and ground-based systems and this involvement should receive every encouragement.

If emphasis is to be placed on VTOL aircraft, then approach and landing phases are critical areas for research and development. Greatly improved procedures are needed, and particularly reliable techniques for blind landing must be developed. Imported technologies are helpful but attention must still be given to the requirements of the Canadian environment.

Undoubtedly, efforts to build maximum reliability into aircraft can go only part way to solve the whole problem. Human factors must receive equal attention. No specific approach to this aspect of the subject is being made in Canada at present insofar as civil aviation is concerned. Services in aviation medicine are supplied by two defence establishments on an informal basis but it may not be practical for these establishments to devote the effort needed in flight safety as it relates to the civil sector, which is a rapidly growing field in its own right. Nevertheless, an institute for the study of flight safety is badly needed in Canada. While it should be established with provision for close co-operation with safety engineers and with particular emphasis on those aspects of "human engineering" that relate to civil aviation, it may be more effective if it can include both civil and military elements.

5. Associated Research Disciplines

In the above discussions the suggested program of research and development in aeronautics has been indicated in terms of various missions considered important to Canada's development. To accomplish these missions evidently certain scientific disciplines must be emphasized. Not only are these disciplines fundamental to the missions, but they are promising fields of research that can lead to new projects consistent with Canadian requirements.

The steadily increasing demands for better performance have led to re-examination of the materials available. In general, only small improvements in conventional materials are predicted and attention is being directed toward the use of composites. Compared with metallic materials, reinforced plastics possess high specific strength, corrosion resistance, electrical insulating properties and dielectric transparency. They are amenable to a wide range of fabricating techniques and versatility in design. The development of composite materials has only just begun. Although major advances have been made in glass-resin plastics, many combinations of organic-inorganic and organic-organic materials still require investigation, especially where particular uses are envisaged. The development and manufacture of composites using reinforcements such as carbon, boron and certain ceramics is already underway in the United States and the United Kingdom.

Clearly acceptable designs of $v/stol$ aircraft, including their power plants, will depend on allowable noise levels. The steady growth of aviation, generally involving greater numbers of aircraft of increasing size and power, has made aerodynamic noise a major problem in aeronautics. Control of aerodynamic noise will only be possible when more is known about its generation, propagation and attenuation. Extensive research is needed, both theoretical and experimental, on all aspects of noise associated with the flow of air.

Another important requirement is the study of large-scale turbulence in the atmosphere and its effect on the stability and control of aircraft. Turbulence patterns peculiar to Canadian conditions must be understood through proper synoptic observation. Experimental studies of stability problems can be done adequately only in recently conceived turbulence-controlled wind tunnels and related flight trials.

While aeronautical research in Canada may emphasize low-speed aerodynamics, it will be necessary to maintain a watching brief on supersonics. The need for competence in this subject arises from operational problems, peculiar to Canada, of supersonic transports and from requirements which must be met if Canada is to participate in the manufacture and repair and overhaul of components for foreign high-speed aircraft.

Blade vibration is a high-priority problem in power-plant design. Both analysis and experiments are needed to determine the relative importance of damping mechanisms, a reliable method for predicting the natural modes of low aspect-ratio, axial-flow blading, the vibration characteristics of shrouded assemblies and the role played by vibration in the onset of fatigue failure.

6. Individual Research Projects

Specific research projects have been given considerable attention by the various Associate Committees, the Department of Transport and the Department of National Defence. Some of these projects are listed in Appendix 14 of this report. The importance of mission orientation in aeronautical research—be it in university, government or even in industry—could be tempered in one respect. A progressive and capable research establishment should have several exploratory, self-propelled projects usually built

around the specific interest of some capable scientist or engineer. Such projects could be permitted to amount to between 10 and 20 per cent of the total effort of the establishment, possibly somewhat less in the case of industry. They would of course be subject to the usual scrutiny as regards progress which should be periodically accorded to all projects in hand.

Government Incentive and Assistance Programs

With regard to the PAIT, IRDIA, IRAP and other federal government incentive and assistance programs, industry has made representations to the government to suggest certain changes in them. It is understood that these changes are being considered. The Study Committee, therefore, does not wish to discuss these programs other than to express the hope that any changes will permit simplified application, approval and funding procedures and will enable the programs to be adapted expeditiously to new situations and circumstances.

The Study Committee also feels that while established companies frequently have greater and better organized resources and may be able to take more advantage of government programs, it should not be forgotten that less well-endowed, newer and smaller companies deserve help too. Also, while the formation and sustension of centres of excellence should be an agreed objective, the federal government should not withhold adequate support from newer, younger, but potentially viable and deserving groups of scientists and engineers. Wider opportunities for graduate students to perform their thesis research in industrial and government laboratories should be fostered.

Chapter XI

Future Canadian Organizational, Management and Advisory Structures for Aeronautical R & D

In Chapter VI a critical examination was made of the present organizations for providing advice and management for aeronautical research and development. The more serious deficiencies were revealed with regard to the effective co-ordination of aeronautical research and development activities within the government and within the country as a whole. The present system does not provide adequate knowledge and understanding among the government officials concerned with aeronautical matters at the senior levels of decision-making. On the other hand, the various Associate Committees of the National Research Council which are concerned with aeronautical subjects have proved to be effective insofar as the discussion of technical problems is concerned and the exchange of information between specialists in government, university and industry. The Technical Advisory Panel (TAP), which co-ordinates the activities of these Associate Committees and attempts to implement their recommendations has been reasonably well motivated but has been less effective than it could have been, owing mainly perhaps to deficiencies in its terms of reference and membership.

A serious weakness of the present organization lies in the senior level which is responsible for taking positive action on recommendations and for seeing that necessary funds are requested. The National Aeronautical Research Committee (NARC) only achieved action indirectly and then only when the recommendations fell within the responsibilities and interest of one of the government departments represented on it. It has no source of funding of its own and no authority for the allocation of funds and therefore cannot achieve the effective participation of universities in the solution of nationally important problems. Equally serious was its failure to gain the support of industry for TAP-originated projects deemed to be of national importance. The major deficiency, however, is that the members of NARC are not in a position to provide that co-ordinated and future-oriented overview of Canada's requirements in aeronautical research and development which the Study Committee believes is essential and urgently required.

In approaching the question of re-organization, a number of important principles which were discussed in the Science Council's Report No. 4, *Towards a National Science Policy for Canada*, have been kept in mind. For example, organizational changes should not be made

just to redress the mistakes of the past but to cope with the progress in the future. The organization should be fully aware at all times of the course of development of aviation in Canada; it should be in a suitable position to recommend priorities and to give overall guidance and co-ordination to all aeronautical research and development activities of government, university and industry. The organization must be able to focus attention on the major problems facing aviation and must be able to ensure that these problems are central to Canada's aeronautical R & D efforts. The organization must be able to break down each R & D program into component projects apportioned as appropriate to government laboratories, university and industry. Programs would be scrutinized on a regular basis to ensure that the objectives are still valid, that the work is proceeding satisfactorily along the right lines and that the funding and expenditures are reasonable and in balance.

The National Aeronautical Research Committee (NARC) should be dissolved and replaced by an Aeronautical Research and Development Board which would be responsible on a continuing basis for overall leadership in aeronautical research and development. There is an important requirement in Canada at this time, and especially in the future, for such a Board. The most important duty of the Aeronautical Research and Development Board would be to recommend priorities and provide that co-ordinated, future-oriented overview of Canada's requirements in aeronautical research and development which is missing under the present system. The members of the Board should be chosen for their breadth of experience, knowledge and understanding of aviation and their current responsibilities in this field. The Board should be representative of both the public and private sectors and the universities and might consist of as many as 12 members. The members from the public service should be selected from the Departments of Transport, National Defence, Industry, Trade and Commerce, and the National Research Council. Those from the private sector should include representation from the airframe, aero-engine, avionic and air transport industries. The aeronautical research community in the universities should be represented, including aviation medicine and "human engineering". Board members should be permitted to receive an honorarium for their services, and should publish an annual report to inform the public of its activities.

The terms of reference of the Aeronautical Research and Development Board should be defined to include such responsibilities as the following:

1. Delineation of the course of aviation in Canada on a continuing basis.
2. Identification of the major needs, opportunities and problems in the areas of aircraft design, development, manufacture and operation which call for research and development effort.
3. Formulation of the requisite co-operative programs of research and development, indicating these important factors:
 - a) Priorities and target dates;
 - b) Appropriate funding levels, and cost / benefits;
 - c) The division of R & D effort between the three performing sectors—university, government and industry.
4. Maintenance of a broad overview of on-going programs of aeronautical R & D in university, government and industry, recommending changes as may be considered desirable.
5. Utilization to the full, of the Technical Advisory Panel, the Associate Committees and such *ad hoc* committees as may be established.
6. Publication of an annual report of its activities.

In trying to visualize how the Aeronautical Research and Development Board might function within the federal government, the Study Committee became aware of the great difficulty of finding a logical and effective channel through which the government could be advised and guided in aeronautical matters. At the heart of this problem lies the fact that the aviation interests of the government are divided among a number of separate departments and agencies. Civil aviation comes under the purview of the Minister of Transport. The Minister of National Defence is responsible for military aviation. The government's in-house activities in aeronautical research are pursued predominantly in the National Research Council's laboratories, which are the responsibility of a third Cabinet Minister. Finally, research and development undertaken in the aircraft industry may be done with government financial support granted under the authority of the Minister responsible for the National Research Council, the Minister of National Defence or, more likely, the Minister of Industry, Trade and Commerce. Financial support for aeronautical research

in the universities can be provided under the authority either of the Minister responsible for the National Research Council, or the Minister of National Defence. In the Study Committee's opinion, none of the departments considered above is clearly the appropriate channel through which the Aeronautical Research and Development Board should communicate with the government.

The possibility that the Board might report to the Standing Committee of Cabinet on Science Policy and Technology, or to its chairman, had much appeal initially to the Study Committee, since all the ministers at present concerned with the various aspects of aviation are members. However, such a channel is not a viable one administratively since the Standing Committee has no statutory authority of its own. In these circumstances the Study Committee accepted the necessity for the Board to report to a single minister who has appropriate authority for some of the aviation matters relevant to the Board's interests.

Because of the relative importance and continuing expansion of civil aviation in Canada, as highlighted in Chapters IV and VIII, the Study Committee concluded that the Aeronautical Research and Development Board should report to the Minister of Transport. This is appropriate in view of his responsibilities for the control and regulation of civil aviation, the airworthiness certification of civil aircraft and their equipments, the provision of airports and all airway facilities such as ground-based navigation, communication and air traffic control systems, the meteorological services, civil aviation safety and accident investigation and the licensing of air and ground personnel. In fact, the responsibility and authority vested in the Minister of Transport under the provisions of the Aeronautics Act include "to supervise all matters connected with aeronautics; to undertake, and to co-operate with persons undertaking, such projects, technical research, study or investigations as in his opinion will promote the development of aeronautics in Canada." The major mission-oriented aeronautical research and development interests of the Board would therefore have a bearing on matters which come within the authority of the Minister.* Where there is overlap with the interests and activities of other departments such as National Defence, Industry, Trade and Com-

*In matters relating to defence, however, "Minister" means the Minister of National Defence.

merce or the National Research Council, the Minister would need the co-operation of his colleagues in the Cabinet who are responsible for these departments. Interdepartmental co-operation would, however, start within the Board itself. For example, since the Department of National Defence is represented on the Board, the Board would be called upon from time to time to give attention to the aeronautical R & D requirements of defence. Again, the Board should be consulted on shared development and contract programs in the aircraft industry. Its deliberations would in all matters be constrained by the magnitude of the budgets for aeronautical research and development available to all the relevant government departments and agencies. However, with direct access to the Minister of Transport, the Board would be in a strong position to advise the government when the need for special expenditures was apparent. The Board should be provided with secretariat services so that its business can be carried out most efficiently.

The Committee considers that these proposals represent the best possible solution. A chart outlining the organizational changes proposed in this chapter is shown in the following figure. At the same time, it is recognized that the aeronautical picture is changing very radically and that the conservative predictions made in Chapter VIII will, within the next decade, face the government with an entirely different situation from that of today. The growth and development of civil aviation will undoubtedly call for a significant expansion in size and capability within the Department of Transport. At that time the decision may well have been taken to attach the National Aeronautical Establishment to the Department after the Department has acquired the technical and administrative competence to make this change desirable and effective.

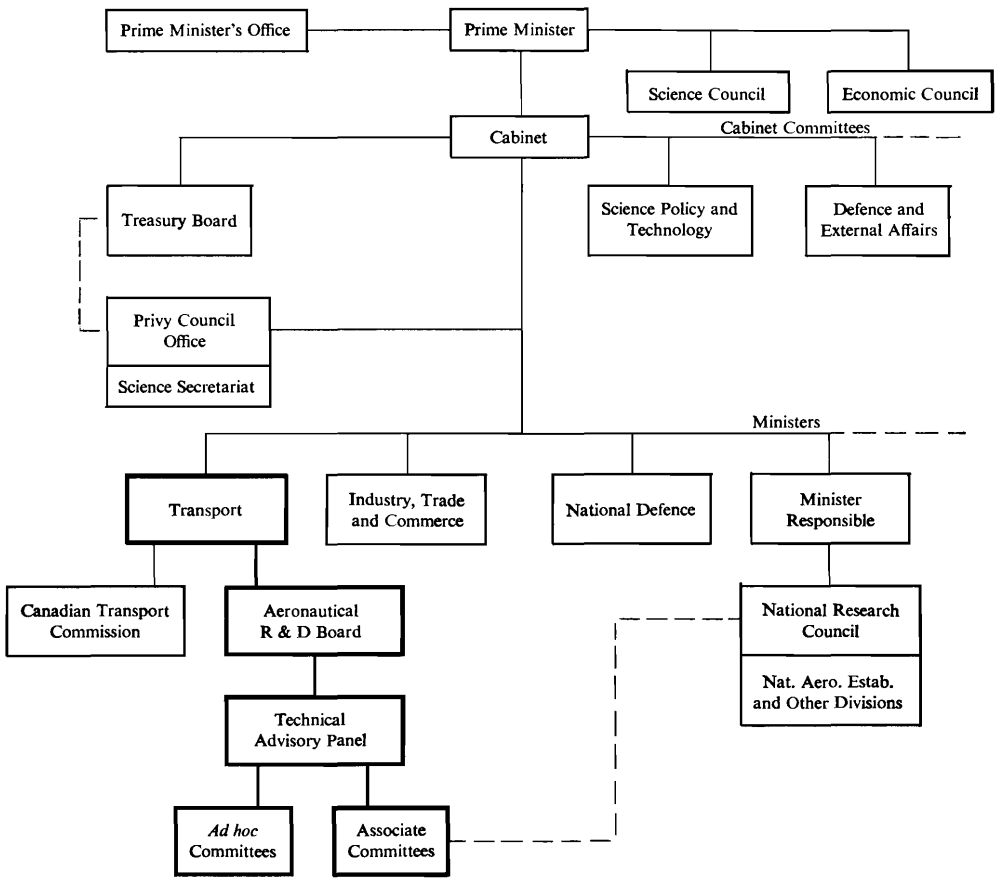
Other possibilities were examined in searching for the best interim solution. For example, the Aeronautical Research and Development Board could be attached to the Canadian Transport Commission instead of reporting directly to the Minister of Transport. This would mean, however, that the regulatory and research segments of the Canadian Transport Commission would have to be separated to a much more positive degree than is the case presently. As a relatively new agency, the Canadian Transport Commission would not yet be in a strong position to accept and implement the recommendations of the Board,

calling as they will for effective co-ordination of research and development effort in university, government and industry. Also, the Commission itself is required to act in an advisory capacity and to give independent judgements to the government.

It is also possible that the Aeronautical Research and Development Board could report to the Minister of Industry, Trade and Commerce. This would be quite acceptable insofar as the aircraft manufacturing industry is concerned, but is less appropriate from the point of view of aircraft operating activities. In civil aviation these are of such an increasing magnitude that the common interests shared with the Department of Transport represent a more compelling argument for the Board to report to the Minister of Transport. With regard to the Department of National Defence, it would appear from the evidence submitted to the Study Committee that civil aviation will be the dominant component of aviation in the next decade and it is quite likely that the involvement of the Department of National Defence with the aircraft industry in Canada will continue to decline. For these reasons it does not seem appropriate to have the Aeronautical Research and Development Board report to the Minister of National Defence.

The Technical Advisory Panel and the Associate Committees should remain in existence and should function more or less as they do now but with the Board replacing the National Aeronautical Research Committee. The work of the Panel could be expected to intensify under such a new and vitalized organization, particularly since the Board would be directing the attention of TAP to nationally important problems. The Technical Advisory Panel should be authorized to establish *ad hoc* committees from time to time, as the need arises, which would be separate from the Associate Committees. It will be necessary to revise completely the terms of reference of TAP to modify their exclusive research orientation and to re-examine the membership to ensure that it is adequately representative of the important sectors. There is an imbalance in the current membership which heavily favours government representation. This should be redressed to strengthen the participation of industry and the universities even if it means increasing the total membership of the panel.

The aeronautical laboratories of the National Research Council are extremely well equipped



and the professional competence of the staff is high. Industry is quick to avail itself of access to these facilities but there remains much scope for closer co-operation on long-range programs; it is believed that the organization outlined above will bring this about. There is a fragmentation of activities in the laboratories and it is suggested that greater effort on fewer projects would produce more timely and significant results. Attempts are made to maintain expertise in some areas where expertise in depth is just not possible, as for instance, where the pace of industrial advance is too intense or the industrial emphasis is shifting rapidly.

The National Research Council is responsive to industry's demands for assistance with current problems. While some of this assistance is commendable, it is believed that it is a mistake for the National Research Council to be too occupied with the present and that it should, at least in some areas, be looking 10 years or more ahead. This would ensure that NRC maintains a degree of leadership in technology. The present tendency is to become deeply involved in exploring the basic fundamentals of current problems while industrial engineers have made their compromises and passed on to a more advanced state of the art. The pace of advance and development is more rapid in technological industry than that which can be maintained in a research laboratory where attention to detail is of primary concern. If this is recognized and accepted, then talented scientists in government can look ahead and engage in long-range programs which can provide basic knowledge and design data in a timely fashion to the industrial engineer when the need arises. The proposed new organization would be expected to follow up the important areas for long-range research discussed in Chapter X.

Most of the aeronautical research facilities of the National Research Council are located in its National Aeronautical Establishment but certain aeronautical work (e.g. on aircraft power plants) is to be found in the Division of Mechanical Engineering. It is believed that this situation should be rationalized and that the National Aeronautical Establishment should encompass the prime aeronautically oriented research activities of NRC. Certain of the aeronautical research facilities are almost completely occupied in meeting the heavy demands of the aircraft industry. Aeronautical facilities both at NRC and elsewhere have proved useful for assist-

ing other, non-aeronautical industries, but such demands have not yet risen to the point where they might curtail or seriously delay the services rendered to the aircraft industry. The aeronautical facilities of NRC have also been made available, at cost, to the aircraft industries of other nations. Although the situation has not yet arisen, it is conceivable that the facilities might one day assist a foreign company which is competing directly with a Canadian company. Under such circumstances it is important that the position of the Canadian company should not be prejudiced.

To summarize, the proposals made in this chapter represent a move towards an effective, mission-oriented organization to serve the needs of Canadian aviation, with a minimum of disruption of those portions of the present organization which are operating more or less effectively. The Aeronautical Research and Development Board must be seen as a radically different body from the National Aeronautical Research Committee. The Committee's terms of reference made it a passive committee which merely reacted to ideas. The Board is designed to be active and to take the initiative in recommending the kinds of programs, goals and emphases which will give Canada a proper place in the aviation of the future. Other countries oriented to aeronautical research and development are setting objectives and providing the management structure to attain them. Canadian failure to do likewise will cause us to fall behind, with little expectation of attaining the position to which our capabilities permit us to aspire.

Chapter XII

Conclusions

As was the case in other countries, the operation of aeronautical research facilities by government and the support of aeronautical developments in Canadian industry were based initially on the requirements of national defence. The situation has changed significantly in recent years and the continued support by government must be justified principally on economic grounds and the present and future requirements of commercial and civil aviation. Aeronautical research and development must be rated as one of the major contributors to a country's scientific and technical advancement. This in itself is a further justification, in this day and age, for government support of aeronautics.

The Canadian scene is radically different from that of other countries. In the dynamic world of today, aviation is vital to the integrity of Canada, providing a rapid transportation link between our linearly disposed population centres. *This report has brought into focus the essential role which aviation and our aircraft manufacturing industry have played, and are expected to play, in the development of Canada and its resources, a development both economic and social.*

The aircraft industry in Canada, as elsewhere, is a high technology industry which has achieved notable successes. It has the highest percentage of exports within the world's aerospace industries. Its annual production has recently been of the order of \$800 million and it provides employment for a substantial number of Canadians. There are large pay-offs from its efforts despite the long lead-times before a product begins to appear. It is this aspect of the industrial activity which has usually won government support and it is so widespread a characteristic that no viable aircraft industry exists in the world today that is not subsidized by government in one way or another, including that of the United States, so closely situated to our own industry. All these and other factors advanced elsewhere in this report argue for a continuation of government support for the Canadian industry. *In the last analysis, however, the intimate relationship between aviation and the development of Canada provides the most persuasive argument for a continuation of government involvement over the entire spectrum of aeronautical research, development, production and operations.*

There cannot be said to exist in Canada any overall stated policy regarding aviation. What does exist are the several policies followed by the various government departments con-

cerned with aeronautical matters, but these are not integrated or significantly co-ordinated. *It may be neither possible nor desirable to have a completely planned environment for aviation, but it is essential that there be a framework within which technological opportunities can be recognized and promptly exploited by industry with well co-ordinated government support.*

From the national point of view, the clearest guidelines for future aeronautical research and development programs and expenditures in this country will be established if there are defined national objectives, or policies related to aviation. In their absence, the objectives and policies of the individual government and university departments and of individual companies play an important role in the programming of Canadian R & D activities. In this kind of situation the problems of conflicting policies and objectives can be very real ones. Through the management, advisory or political structures there will have to be more mission orientation in future Canadian aeronautical research and development, more collaboration and co-operation between the performing departments, companies and laboratories. The initiatives taken to exploit good Canadian scientific and technical ideas and market opportunities must not be frittered away.

The exchange of information and the co-operation between university, government and industry needs to be enhanced by a stronger, more involved and more active organization at the top levels. At the working level, the exchange of information between specialist committee members is excellent, especially as regards immediate or short-range problems. From the point of view of long-range co-operative planning of important aeronautical research and development programs, however, the existing organizational arrangements are woefully inadequate. Discussion of ways for rectifying this is contained in the foregoing chapter. *The success of aeronautical research and development depends on good overall leadership and the establishment of many bridges between people in university, government and industry.* It is not simply a matter of having a group of laboratories, a few committees and the reading of papers at scientific meetings.

Generally, a large percentage of aeronautical research in Canada should continue to be performed in the universities and the majority of development work in industry. Gov-

ernment-performed activities in both fields should anticipate industry's longer term needs rather than supplement the work of the universities or cover fields of current industrial interest. However, in certain circumstances, government-owned facilities, including aircraft, may be the only appropriate means through which some university research and industrial development can be performed. Technological capability is of great importance in obtaining production contracts. These facilities should also continue to be available under appropriate contract terms and conditions to foreign research and development organizations and when clear benefit to Canada can be foreseen. *The distribution of federal funds to support aeronautical research in the universities should reflect a recognition of the important role of the centre of excellence.* The Study Committee concluded that where universities are concerned, for mission-oriented projects, it would be beneficial to have more research going on in fewer places. This does not mean, however, that the government should withhold adequate support from newer, younger, but *potentially viable* groups of scientists and engineers.

The concept of Canadian government support for aeronautical research and development in industry should not be an annual "pot of gold" but a carefully co-ordinated support for selected projects which are mission- and market-oriented. The industry is anxious to preserve its independent capability to design, develop, manufacture and market competitive aircraft. This is a desirable national objective and worthy of support if the types of aircraft are tailored to the market demands, domestic and export, and are within our technical and financial resources. *It is important for government to recognize opportunities for true innovation and to encourage industrial initiatives to apply technology.* Strong and effective innovative activity is essential for dynamic and competitive progress in this industry. The augments wing concept and the small gas turbine engine design concepts are typical examples of advanced technical ideas which should be encouraged. *Especially important is the need to consider how best to promote projects which promise to yield substantial, rather than marginal, improvements in performance over what is available today.*

Earlier in this report concern was expressed that the likely continuing decline in domestic military aircraft requirements and the possibility of adverse changes in the opportunities

of the export market would necessitate greater reliance by our industry on the various possibilities offered by civil aviation. Indeed, the ultimate survival of the industry might have to be based predominantly on these prospects. One of the greatest challenges to the manufacturers of aircraft, avionics and accessories in this country should stem from the fact that at the present time more than 90 per cent of the aircraft being flown in Canada were not designed or developed in this country.

The government has fostered defence production and defence development sharing programs with the United States. Through existing industrial links between U.S. companies and Canadian subsidiaries there could develop an increasing production in Canada of U.S.-developed equipment both military and commercial. If this is properly handled, the financial and technical climate in Canadian industry for product improvement, development and innovation would be enhanced. The industry must strive to expand its participation in the engineering and production of sophisticated military and commercial aircraft systems and the government should encourage the timely transition to industrial rationalization which is economically sound.

As far as complete aircraft are concerned, the principal Canadian aeronautical R & D activities should be built around the existing capability to design and develop STOL aircraft systems. There will also be opportunities for the design and development of special aircraft for world markets which also take into account Canadian requirements. Since the supersonic and large commercial aircraft market are patently beyond our industrial capabilities, it is worth examining the market now served by the high-productivity, low-cost manufacturers of small aircraft such as Beech, Cessna and Piper. While we have the requisite design and development talents, the manufacturing and marketing opportunities in this field simply do not exist at present. The anticipated growth in demand for this type of aircraft within the next decade, however, may justify a consideration of the possibilities of some worthwhile penetration of this market by Canadian industry, using its STOL experience as a base.

In the formulation of aeronautical research and development programs, it is essential that this mission-oriented applied science should be looking some 10 years ahead, or more, to envisage the type of product which buyers may

want, the performance alternatives, and the relevance of changing environmental conditions. Many of the problems now facing U.S. aviation have become chronic and call for immediate action. Many of those facing us in Canada are not yet chronic and we have time to solve them by initiating the appropriate R & D programs. The argument raised in Canada recently regarding the extent of support as between university, government and industry would be resolved by the kind of co-operative programs envisaged here. The results would be a division of effort based on capability and timing constraints in the best interests of the specific programs and the long-range requirements and interests of the three sectors.

The establishment of a program of research and development in commercial STOL and V/STOL aircraft could bring into focus the efforts of all three sectors to accomplish a national objective capable of major contributions to Canada's technological progress, industrial competence, efficiency in transportation, and to the export market.

It is concluded that the existing program of research, design, development, manufacture and sale of small- and medium-thrust engines ought to be considered for enlargement and acceleration as one of Canada's high-priority objectives in aeronautics.

The field of avionics is one of steady growth and expansion. Canadian companies have made notable contributions and are fully up-to-date and capable in the basic technology. *The costs and complexities of development programs in avionics do not produce the same pressures which have forced us out of the military aircraft design and development field. The underlying technology (electronics) is perhaps central to the major technical developments which are taking place in the world. For these and other reasons this field of activity should commend itself to government as being especially attractive from the economic, social and technological points of view.* Here again, the support should be selective, with careful consideration being given on a project-by-project basis. It is becoming accepted today that strong government support is only given to those programs which have a very high probability of producing an item which will lead to a large production run. The costs of innovation in the avionics and accessory equipment fields are difficult to forecast, for, besides R & D costs, the costs of regulatory qualification and marketing a new equipment concept have to be included. Companies which

have a "tie-in" with a dominating commercial product—such as a particular type of aircraft—may plan their R & D expenditures with some assurance of an eventual return on their investment. In reverse, the lack of a "tie-in" will have adverse effects on the R & D-innovation process in many cases.

The evolution of aeronautical research has shown that it has of necessity concerned itself with the problems of aircraft design and development and less perhaps with the problems of the operators. *In Canada, where aircraft operations have become a big business, it is highly desirable to see more of our research effort directed to the present and future problems of the aircraft operators.* Because of its shortcomings as a good neighbour and the residual deficiencies in its performance of the services expected by the travelling public, commercial aviation will be subjected to increasing social pressures to improve its performance on both counts. Good teamwork between government and industry will be necessary to achieve progress in solving the problems. It is noted that the aircraft accident statistics of the world, measured by the rate per 100 million passenger-miles, are not improving with time, leading to the conclusion that there will be more accidents as the volume of flying increases. *It is concluded that an aviation safety centre should be established in Canada which would be the focal point for an intensive and continuing drive on the many kinds of problems which are constantly arising to thwart our efforts to attain complete safety in air operations.* It should be established with provision for close co-operation with safety engineers with particular emphasis on those aspects of "human engineering" that relate to civil aviation. The possible extension of its responsibilities to include military aviation safety should be considered in view of the mutual benefits which could accrue to both civil and military operations.

Canada has also made great contributions in the past in aviation medicine. Our efforts are now fragmented and diluted and we have no central organization to serve civil and military aviation. Yet the rapid expansion of civil aviation and the growth in performance of civil aircraft has led to a situation wherein many people who are concerned with civil aircraft operations are ignorant of some of the important physiological factors on which human safety in flight depends. *It is therefore concluded that an aviation medicine centre should be established in Canada to handle*

research and development in this field and to undertake the necessary role of education of the flying community. Presently such work is done within the Canadian Forces, in one other government establishment, in the universities and within the medical profession elsewhere in Canada. Here again we should not separate our efforts to satisfy civil and military interests, since the problems are usually common to both, but we should create a single centre to cater to all our needs. In creating such a centre the existing facilities and capabilities should be utilized but the new organization could well be linked to one of our universities or conceivably it could be an integral part of the broader aviation safety centre suggested above.

Modernization of the navigation and air traffic control systems by the Department of Transport will permit such systems to cope with the expanding problems stemming from increased traffic and operations under adverse weather conditions. This will look after the main airway system. However, the growing volume of private flying calls for special low altitude capabilities and for navigation facilities which are either nonexistent or inadequate for the private flying requirements in certain areas of the country.

Because participation by the government in the administration of aircraft design, development and procurement has been intermittent, we have lacked the permanent organizational structure which in Britain or the United States has gone a long way to ensure that the aeronautical research undertaken in government laboratories, or indeed in the country as a whole, is closely co-ordinated with the current and future needs of aviation. As discussed in the previous chapter, the Study Committee is firmly convinced that a co-ordinated, future-oriented overview of Canada's requirements in aeronautical research and development, and subsequent implementation, are essential and that *an Aeronautical Research and Development Board should be established and should be responsible on a continuing basis for overall leadership in aeronautical research and development.* The Study Committee hopes that this report may serve as a useful basis for the initial work of this Board, as it begins to move forward to examine the future problems, needs and opportunities in the field of aeronautical research and development in Canada.

Appendices

Appendix 1

Historical Aspects

1900 to 1920

The blowing in of the world's first great oil gusher (Spindletop) in January, 1900, followed by the first controlled flight of a heavier-than-air machine by the Wright brothers on December 17, 1903, were but the prologue to a story which identifies the twentieth century as undeniably the century of aviation. For in the 66 years since then, lavish expenditures by governments and industries have enabled scientists and engineers to achieve developments and advances at a rate unapproached in any other field of human endeavour. Although the honour and fame for the first successful flight belongs to the Wright brothers, other experimenters in the United States, France, England, and Germany were pressing forward more or less along similar lines and it seems in retrospect that the attainment of mechanical flight was inevitable. Certain it is that the success of the Wright brothers' efforts was due to the methodical way in which they identified the basic problems of controlled flight, their careful experimental work and their reliance on sound engineering principles in the design and construction of their first aircraft. They could not have realized at the time that they were establishing a pattern which was to persist through all the great adventures and advances which aviation was destined to experience.

Encouraged by the growing successes of the Wright brothers, pioneers in other countries, including Canada, pressed forward and were able to achieve mechanical flight also. By 1914, when World War I broke out, progress had been sufficiently convincing to conclude that aircraft would be able to play a useful military role. This role was not decisive for the outcome of that conflict, but it left no doubt in the minds of many men of perception that the day was not far off when "air power" would be a decisive factor. It was certainly this realization by the major powers that led to the establishment, at about that time, of the agencies and organizations which could best accelerate the progress of military aviation. As a secondary benefit, civil aviation was expected to thrive on the technological "spin-off" from military R & D programs.

Aeronautical activity in Canada has been directly and indirectly affected by progress in

the United Kingdom and the United States. An examination of past and present aeronautical research and development in Canada ought not to be done in isolation, therefore, but should be undertaken within the context of aeronautical activity in these countries, and particularly the United States with which we have such an important interface.

The United Kingdom, 1900 to 1920

The great strength of British aeronautics in the early decades of this century resulted from the attraction of men of culture and education to it. Beginning with Sir George Cayley, who in 1809 described precisely how mechanical flight would be achieved, and others who followed him during the last century, a pattern was established wherein the scientific problems of mechanical flight engaged some of the most brilliant minds in Britain. The National Physical Laboratory (NPL) had begun to do aeronautical research in 1909. During World War I, both the National Physical Laboratory and the Royal Aircraft Establishment (then known as the Royal Aircraft Factory) were staffed by some of the most outstanding men and women scientists whose work, along with that of scientists in France and Germany, is part of the history of aviation and aeronautical science. When the war ended, many of these scientists continued their work, some returning to universities to found departments of aeronautics, to teach the subject at postgraduate level and to do research. The significance of aviation to warfare had been demonstrated sufficiently for the British government to take the step of creating, in 1918, an Air Ministry and a separate flying service, the Royal Air Force (RAF).

On the development side of aviation it soon became obvious that the twin demands for increasing reliability and greater performance—demands which are still dominant—could only be met by refinements and advances in engineering. Someone once remarked that aeronautical engineering is ordinary engineering made more difficult, but this is an oversimplification. In World War I the demands of aviation invoked a revolution in the lumbering industry to produce high quality grade A spruce, raised to the status of an engineering material for the primary structural components of military aircraft. This has consistently been the story ever since. The stringent requirements of aviation have stimulated in turn the improvement, often beyond what could have been foreseen, of such materials

as fuels and lubricants, dopes and varnishes, high tensile steel, high strength aluminium alloys, high temperature alloys and so on. Every advance in safety and performance over the years has been won, but grudgingly, at the cost of months or years of unflagging development work, undertaken in the most rigorously scientific manner in countless laboratories of government and industry in many countries.

To complement the NPL and the RAE and to provide an agency for the assessment of military aircraft and their equipments, with a view to their acceptance by the Services, the Aircraft and Armament Experimental Establishment (A and AEE) was created in 1917. For some years the A and AEE was responsible also for the airworthiness flight trials of British civil aircraft. In World War I the Royal Aircraft Factory was a War Office station. When the Air Ministry was created after the war, the renamed Royal Aircraft Establishment was transferred to its control, along with the A and AEE, reporting to the Director of Scientific Research at Air Ministry Headquarters. Government sponsorship of both military and civil aircraft development, production and procurement* was handled by the same Ministry also. Through the co-ordination made possible by this organization the government tried to ensure that programs undertaken at the establishments had, at all times, a direct relevance to the current needs of aviation development and industrial activity.

To provide a continuing liaison between government establishments and the basic aeronautical science of the universities, an

Advisory Committee for Aeronautics (now the Aeronautical Research Council) came into existence in Britain in 1909. Its membership is drawn roughly equally from government and universities with, in later years, the inclusion of some industrial scientists. Over the years the Aeronautical Research Council has had a strong effect on the scope and direction of aeronautical research in Britain and some influence on the course of British aircraft development.

The United States, 1900 to 1920

Despite the tremendous advances in military and civil aviation in the United States since World War II, the early years were characterized by frustration, pessimism, and a lack of public support and enthusiasm. The Wright brothers found recognition and fame in France rather than in their own country, and certainly in the early years, France was the world centre for aviation activity and enthusiasm.

The French government was easily the first to recognize the possibilities of aviation in warfare and this, added to an intense interest in aviation on the part of the French people, created a most favourable climate for its development. French aircraft such as the *Bleriot*s, *Caudron*s, *Farmans* and *Moran*es became popular at flying schools in France and England. On the scientific side the work of Professor G. Eiffel at his aeronautical laboratory in the Eiffel Tower drew wide attention not only from scientists but from aircraft designers who valued the practical nature of the results he produced.

*When current military aircraft were due to be replaced in service by new types, the Air Ministry would initiate a design competition within industry and would issue specifications detailing the operational and performance characteristics desired for the new aircraft. Quite often, however, the industry had a better appreciation of what might be achieved. Some of the finest, and at the time the most advanced aircraft, for example the Hawker *Fury* of 1929 and the Supermarine *Spitfire* of 1935, were private venture types not designed to meet an Air Ministry specification but nevertheless accepted for service on the basis of potential or demonstrated superiority over contemporary types.

The encouragement and sponsorship of civil aircraft was much less satisfactory, perhaps because there was not always a single customer, as in the case of the RAF, perhaps because civil aircraft development was viewed as an exercise for private enterprise or perhaps because civil aircraft development was still the stepchild of military aircraft development. In 1919 a Department of Civil Aviation was created within the Air Ministry, but to quote Sir Henry Self, "between the two World Wars government support and encouragement of the develop-

ment of civil aircraft was sporadic and there was no serious governmental attempt to create and build up a civil branch of the aviation industry until the Cadman Committee (1937) indicated the probable results of past neglect and strongly recommended State assistance to encourage the development of suitable types of civil aircraft." The government thereafter appointed a Director of Civil Research and Production with a small technical staff in the Department of Civil Aviation and took additional promising steps which were unfortunately negated by the outbreak of war. In October, 1944, Britain effected some separation of civil and military aviation by establishing a Ministry of Civil Aviation, but she left the responsibility for the design and production of civil aircraft, as well as military aircraft, under the Ministry of Aircraft Production. The two functions have remained together under one ministry ever since. To offset possible disadvantages which this arrangement might have for civil aviation, an interdepartmental committee, the Transport Aircraft Requirements Committee, was established in 1946 (and is still functioning) to ensure short- and long-term action to improve Britain's civil aircraft production situation.

Besides lack of popular support, the United States did not have the numbers of university-trained scientists interested and active in aeronautics that Britain had, and its industry was negligible. In the mid-1920s she lagged far behind. In 1915 Congress established the National Advisory Committee for Aeronautics (NACA; now the National Aeronautics and Space Administration, NASA) "to supervise and direct the scientific study of the problems of flight, with a view to their practical solution." The NACA remained a small organization for 25 years. When World War II erupted in 1939, its total staff was but 523, of whom only 278 were engaged in research activities. Yet the NACA has had a tremendous influence not only on American aviation but on world aviation also. The members of the NACA—the "Main Committee", as the policy-making body of the new organization came to be called—were appointed by the President and served without compensation.

To quote from Professor Jerome C. Hunsaker*: "The committee acts like a board of directors in guiding a research staff numbering more than seven thousand...Its research has, for a generation, laid the groundwork for aeronautical advance in this country. That its efforts have been effective is perhaps best attested by the acknowledged superiority of the aircraft designed and produced by the American aircraft industry...Our transport planes are the standard equipment of most of the world's air lines." If these statements were true in 1952, how even more valid have they become in 1969!

Canada, 1900 to 1920

The contribution made by Canada began when aviation was in its infancy. W. Rupert Turnbull of Rothesay, New Brunswick, constructed the first Canadian wind tunnel in 1902 and in later years he made valued contributions to both aeronautical science and development. In 1907 Dr. Alexander Graham Bell's "Aerial Experiment Association" was formed of five members, including two Canadians, J. A. D. McCurdy and F. W. (Casey) Baldwin. This group designed and built a number of successful aircraft in one of which, *Silver Dart*, McCurdy made the first controlled flight in Canada on February 23, 1909. In August 1909, McCurdy and Baldwin made demonstration flights with the *Silver Dart* for

the Department of Militia under most unfavourable conditions of terrain and wind at Petawawa, which led to destruction of the aircraft. The authorities remained unconvinced of the practical military value of aircraft and declined to give any assistance in furthering the development of aviation.

Less than a decade later, in December, 1916, Canadian Aeroplanes Ltd. was established in Toronto by the Imperial Munitions Board, to provide aircraft for the Royal Flying Corps training units in Canada. Some 2 900 Curtiss JN-4 (*Jenny*) aeroplanes were manufactured, 1 000 of which were diverted to the United States to offset their production slippages. Also, 30 twin-engined Felixstowe F3 and F5 flying boats (the largest type then in existence) were built in 1918 for the United States Naval Services. As World War I drew to its close, mass production of Avro 504 trainers was just beginning. As in a later conflict, Canada did an outstanding job in pilot training. The Royal Flying Corps units in Canada turned out 3 470 trained pilots. To this number must be added nearly 700 pilots trained for the Royal Naval Air Service by the Curtiss Flying School established in Toronto by J. A. D. McCurdy in the spring of 1915. These pilots earned a great and lasting reputation for Canadian courage and ability in the air and proved later to be a priceless asset in the opening of the remote areas of Canada and in its exploration and survey by air.

In 1917 J. H. Parkin, who was on the engineering teaching staff of the University of Toronto, received authorization to create an aerodynamic research laboratory. Parkin had long been interested in aeronautics and had closely followed the published literature dealing with its scientific and engineering progress. He was familiar with both the theoretical and experimental work in France, Germany, the United Kingdom and the United States and was present when the famous French pilot Count Jacques de Lesseps made demonstration flights in Toronto with a *Bleriot* monoplane during July, 1910. Later, Parkin built an exceptionally fine scale model of this aircraft which won him a prize. One of the most important things he did was to plan and initiate the first undergraduate course in aeronautical engineering in Canada. Meanwhile, published papers on his aeronautical work attracted wide attention. In 1918 the University of Toronto constructed its first wind tunnel, followed in 1923 by a more efficient tunnel of the same size.

*Aeronautics at the Mid-Century. Yale University Press, 1952.

The Canadian government was quick to realize that aviation would have a special significance for this country and in June, 1919, it created the Air Board with broad powers to control all forms of aeronautics, and specifically to regulate civil aviation. During the war (late 1916), the Honorary Advisory Council for Scientific and Industrial Research (NRC) had also been created. Anticipating a requirement for aeronautical research, the newly established Air Board requested NRC to form an Associate Air Research Committee (later, the Associate Committee on Aeronautical Research) which was done in 1920. Later in that year a civilian engineer, E. W. Stedman, was appointed Director of the Technical Branch of the Air Board. Stedman had been a senior assistant in aeronautics at the National Physical Laboratory in 1914 and on the outbreak of war joined the Royal Naval Air Service. He was therefore quite familiar with the scientific strength underlying British aeronautics and his own wartime service was testimony to his belief in the military importance of aviation. He had a very great influence on aeronautical research and development in Canada over a period of about 30 years. The Air Board ceased to exist in January, 1923, when its functions were assumed by a new Department of National Defence. Stedman was one of the first to join the Royal Canadian Air Force when it came into existence in 1924 and he continued to provide the leadership and responsibility for technical matters.

The United Kingdom, 1920 to 1930

In Britain there was a hiatus in aircraft development when World War I ended and production orders were cancelled. But plans for aviation were going ahead. The delegates to the Peace Conference envisaged a worldwide airway system for the carriage of passengers, cargo and mail with the result that an International Convention for Air Navigation was created to establish some general principles. In August, 1914, plans had been well advanced for a trans-Atlantic flight but the war ended that. Interest was revived immediately after the war and with the stimulus of a *Daily Mail* prize, the Atlantic was spanned in 1919. In May, a U.S. Navy Curtiss NC-4 flying boat crossed from Newfoundland to Plymouth with stops at the Azores and Lisbon. The following month Alcock and Whitten-Brown flying a Vickers *Vimy* bomber won the 10 000 pound prize for a non-stop flight

from Newfoundland to Ireland. Four subsidized companies began to operate cross-channel services but in 1924 these arrangements were terminated when the government created Imperial Airways to operate all international air services. By 1930 this company's annual traffic in ton-miles had grown to more than one million. Early British transport aircraft were predominantly modified Handley Page, Vickers *Vimy* and other bombers surplus at the end of the war. In France, however, Farman and Breguet were building commercial transports of new design and Junkers all-metal monoplanes were being produced in Germany.

In 1925 Geoffrey de Havilland designed the famous DH 60 *Moth*, the first successful light aircraft, which did so much to popularize flying, bringing it within the reach of thousands of average men and women and ushering in the decade of long distance solo flights. The 1920s also saw the first successful British rotary wing aircraft, the Cierva Autogyro, and the last of Britain's great airships, R. 100, and the R. 101, the tragic loss of which put an end to British lighter-than-aircraft for all time.

The United States, 1920 to 1930

In the United States, the development of new types of aircraft was inhibited by the large quantities of war surplus aircraft. Military aviation was retarded by the opposition of old-line generals and admirals, the court-martial of General William E. (Billy) Mitchell exemplifying the conservative views regarding aviation which were current at senior levels. The most important event in U.S. aviation in the 1920s was Charles Lindbergh's 33-hour solo flight from New York to Paris in 1927, undoubtedly the greatest solo flight in history. Not only did this event have a tremendous impact all over the world, but overnight it jolted the American public from apathy to enthusiasm for the "air age" and at last won public support for commercial aviation; airline stocks skyrocketed. Military aviation benefited too and could look forward to the assumption of its rightful place in the fighting services.

Canada, 1920 to 1930

For the fledgling civil aviation, the post-war slump in Canada was as great a challenge and hurdle as it was elsewhere, and the climate did not improve until the late 1920s. Yet in the earlier years of the decade, im-

portant pioneering flights were made across Canada, to the Arctic Circle and beyond, by veterans whose names and exploits in those years of the first bush pilots have become woven into the fabric of Canadian history. These were the dawn years of exploration, forestry patrol, photography, survey, prospecting and just plain transportation, when aviation alone held the promise of meeting most of the requirements. Great knowledge and experience began to be accumulated in combating the problems of weather, topography, navigation and survival. Pilots and engineers, who pitted their abilities against a host of natural obstacles and prevailed, developed a resourcefulness and skills which are legendary.

When the Air Board disappeared in 1923, the administration of civil aviation was passed to the Department of National Defence. This proved to be somewhat unsatisfactory and some rectification was made in 1927 when civil aviation, civil government air operations and aeronautical engineering were placed directly under the control of the Deputy Minister. The Royal Canadian Air Force remained as a separate service within the Chief of the General Staff's Branch. Civil aviation continued to be administered by the Deputy Minister of National Defence until 1936, when it was transferred to the new Department of Transport. The civil government air operations, based on the forest services of the prairie provinces, were conducted by the RCAF until 1931 when these provinces took over control of their own resources from the federal government.

The Canadian aircraft industry was born in this decade of the 1920s. Canadian Vickers was the first, beginning in 1923 with a contract for the manufacture of Vickers *Viking* amphibian aircraft designed by the parent company in Britain. The following year the company expanded its activities by designing aircraft to meet Canadian requirements. Mr. W. T. Reid, the chief engineer, and his team, produced a number of successful aircraft among which the *Vedette*, *Vancouver*, *Varuna* and *Vanessa* are worthy of mention. Models of all or most of Reid's aircraft were tested by Mr. Parkin in the University of Toronto wind tunnel. The aircraft themselves proved most useful for forestry survey and photographic work. In 1927 the company was bought by a group

of Canadian financiers and struggled to survive with a handicap of 7 per cent bonded indebtedness. The chief designer left in that year to found his own company, which later became the Curtiss-Reid Aircraft Company. Canadian Vickers' situation was not helped when civil government air operations were transferred to the provinces in 1931 and an order for 12 *Vancouver* flying boats was cancelled. The Fairchild Aircraft Company in the United States had designed aircraft which also proved useful in Canadian operations and Canadian Vickers were licensed to produce these aircraft in Canada. This arrangement lasted until 1929 when a subsidiary of the Fairchild Company was established at Longueuil, Quebec. Vickers then turned to the manufacture of Fokker *Super-Universal* aircraft, another type which found favour in bush operations. When the Wall Street crash of 1929 and the subsequent depression occurred, Vickers' design team, representing over 250 man-years of design experience, was dissipated. The Curtiss-Reid company was taken over by the Noorduynd Aircraft Company in 1935, which was itself absorbed by Canadair after the war.

The de Havilland Aircraft of Canada Limited was established as a branch plant in 1927 for the assembly and service of D.H. aircraft designed in Britain. Three aero-engine companies were also established in Canada in this decade—Armstrong-Siddeley Motors, Ottawa, and the Canadian Wright and Canadian Pratt and Whitney Companies in Montreal. To give some indication of this industrial activity, between the years of 1923 and 1936, some 677 aircraft were built or assembled (about 200 of these at Canadian Vickers) as were 260 aero-engines.

As for aeronautical research in these years, the only significant facilities were those operated by J. H. Parkin at the University of Toronto. Here, in addition to model aircraft tests for the young industry, modest research programs were undertaken as a contribution to aircraft design knowledge. At other universities in Canada engineering faculties tackled the practical problems imposed on aviation by our winter climate. These centred on the operation of aircraft engines, particularly their starting at low temperature, lubrication and cooling and the low temperature characteristics of oil and structural materials. Turnbull designed his electrically controllable pitch propeller which, with the sponsorship of the Associate

Air Research Committee, was tested at RCAF Station Camp Borden in 1925.

As this decade drew to its close the government authorized the construction of laboratories for the National Research Council and these included facilities for aeronautical research which were, in fact, given construction priority. Mr. J. H. Parkin was appointed as head of these facilities which later formed the nucleus of the Division of Mechanical Engineering. Three major installations were constructed: a wind tunnel, a towing basin for the testing of seaplane floats and hulls, and an engine laboratory for type testing and research on aero-engines.

The United Kingdom, 1930 to 1940

The economic depression of the 1930s produced some quite anomalous effects. In Britain, judging from the way in which aircraft design was evolving, the depression appeared to have little serious influence. For this was the decade in which British designers adopted all-metal structures, introduced metal in place of fabric as a wing surface material, finally turned their backs on the biplane in favour of the monoplane, introduced the retractable undercarriage and generally began to perfect the streamlining of aircraft which, coupled with advances in engine power, resulted in much improved performances. As this progress was being made in design, the burgeoning commercial aviation business was introducing a revolution in transportation. Britain's major contribution was in the development of air routes to India, Australia and South Africa. She also participated in the European network of airways which began to take shape at this time, and as the decade drew to a close, Britain and the United States had pioneered a trans-Atlantic mail run using flying boats for the purpose.

The United States, 1930 to 1940

A similar picture of fairly healthy activity existed in the United States although the depression was much more in evidence. Despite its late start, the United States was able to build up, within a decade, an airway system that was without equal. Its growth was not restricted to the continental United States but ranged far across the Pacific. As for equipment, the aircraft industry began producing the first of a long series of famous commercial aircraft. The Clipper ships of Martin and Sikorsky in 1933

and 1934, DC-1 the first of the famous Douglas series in 1934, the DC-3 in 1935, the first DC-4 four-engined airliner in 1939 and the first pressurized high-altitude Boeing *Stratoliner* in the same year.

In both Britain and the United States aeronautical research proceeded steadily, still operating on the philosophy that it was primarily a defence requirement which, as a bonus, also benefited civil aircraft development. That it was effective can best be gauged by the excellent progress in military and civil aircraft design and development. During this time, too, some of the more serious problems in aviation such as the spinning of aircraft and wing flutter were largely overcome by systematic research programs which not only provided a better understanding of these phenomena but also the information to enable aircraft designers to avoid such troubles.

Canada, 1930 to 1940

In Canada, aeronautical research suffered both directly and indirectly from the depression. Government curbs on spending precluded any increase in the staff, which was but a mere handful, or any extension of the facilities. The RCAF suffered drastic cuts in personnel with all non-permanent positions cancelled and its operations held to a minimum. The manufacture and sales of aircraft stagnated during the depression and there was accordingly very little demand on the NRC aeronautical laboratories to assist the industry. The Fairchild Company of Longueuil designed three new aircraft, the *Super 71*, the *82* and the *Sekani* but only the *82* proved to be a successful venture and became popular as a bush transport aircraft. Another very successful project was the Noorduyn *Norseman* which first flew in November, 1935, five months after the *82*. It became the greatest and most adaptable single-engined transport for use in remote areas of the world and it quickly made a reputation for itself, a favourite on wheels, floats or skis. Both the *82* and its competitor the *Norseman* were designed without any reliance on wind tunnel or other laboratory tests.

In contrast, commercial aviation during the decade of the 1930s, as measured by the tonnage of mail and freight carried, showed a remarkably healthy growth. Most of this activity was in support of the mining communities and prospectors scattered throughout the interior of the country and for the

benefit of outlying districts in the east and west. Aircraft penetrated to the remotest of settlements and travel by air became the only acceptable method for moving men and supplies over hundreds of miles of virgin territory. In 1929 some 3 900 000 lbs. of freight and 430 000 lbs. of mail were air-lifted, but by 1939 the figures had risen to 19 380 000 lbs. and 1 900 000 lbs. It is impossible to portray in words or numbers the tremendous impact that aircraft had on the development of our "north country", a social role that has continued unabated over the years, making the aircraft an indispensable factor of life and permeating almost every facet of it. Despite all this healthy activity, few problems were discovered to engage the attention of the aeronautical laboratories. The RCAF remained as the prime "customer," although the tasks undertaken were all of an *ad hoc* nature and mostly of a non-military character. The tradition of looking to the laboratories for the support of development and problem-solving was still strong and commendable, however. It was difficult to generate the same notion in civil and commercial aviation circles which tended to live with their problems at that time.

It was not believed in government circles that commercial aviation development would be confined for long to the more remote communities. As early as 1927 it was foreseen that a trans-Canada airway system would be imperative if we were to keep pace with developments in Europe and the United States. Survey work commenced in 1928 and by 1930 much of the system, including the intermediate aerodromes and facilities in the prairie provinces, had been completed. During the depression, construction of the aerodromes proceeded as an unemployment relief scheme until July, 1936. Thereafter the tempo of construction was increased and the coast-to-coast system was virtually complete at the end of the decade. Trans-Canada Air Lines (now Air Canada) came into existence in 1937 and commenced operations on the Vancouver-Seattle route in September. Originally it had been intended that TCA would be jointly owned by the Canadian National Railways, the Canadian Pacific Railways, and Canadian Airways Limited (created in 1930 by a merger of all companies holding interurban mail contracts). At the last minute the CPR and Canadian Airways Limited withdrew from the project, leaving the CNR with full ownership of the

new airline. Three years later the CPR began to acquire the larger air carriers, including Canadian Airways Limited, to create Canadian Pacific Airlines, the process being completed by the end of 1941.

With the end of the depression and a realization that the European situation could lead to another world war, the National Research Council made plans for the design and the construction of new and better aeronautical research facilities, with every expectation that they would, in the event of war, be subject to heavy demands from the RCAF and the aircraft industry. A somewhat larger wind tunnel with a much higher speed capability was built and a modern spinning tunnel was added. A comprehensive engine laboratory and a larger model testing basin were provided. Also, a laboratory for aircraft structural research, a fuel and lubricant laboratory, an aircraft instrument laboratory and a low temperature testing facility were all included in the modernization program.

The United Kingdom, the World War II Period

The outbreak of war in Europe was characterized by an almost total reliance on air power in combination with armoured mobility on the ground. For Britain, as she battled to gather her strength, aircraft production was a critical factor and thereafter, throughout the conflict, development and production remained of supreme importance. Britain's aeronautical research facilities were fully occupied in a supporting role to development. World War I demonstrated that military aircraft performance depended critically on engine power and over the span of that conflict engine power was tripled. In World War II aero-engine development led almost to a quadrupling of power output. Since superior altitude performance was often the decisive factor in aerial combat, supercharger development was of primary importance. By 1944 it was evident in both Britain and the United States that pushing the development of the piston engine to higher and higher power had just about reached the limit. Fortunately by that time the gas turbine had been sufficiently successful to hold the promise of vastly increased power which could be used either to drive a propeller or to provide a jet propulsion power plant. Although Professor Heinkel in Germany flew the first practical gas turbine powered aircraft in August, 1939, and the

British Gloster Whittle jet aircraft flew in May, 1941, A. A. Griffith at the Royal Aircraft Establishment was working on gas turbine compressors as early as 1926. Whittle and the Rolls Royce Company deserve the full credit, however, for giving the United Kingdom its dominant lead in this field. Germany also continued the development of the gas turbine during the war but was not in a position to exploit her own lead in the immediate post-war period.

The United States, the World War II Period

A similar, if less embattled, picture of aeronautical design, development and production was presented by the United States and a number of famous aircraft were in quantity production. Besides the *Harvard* trainer, so familiar to our skies (and ears), bomber aircraft typified by the DB 7 *Boston*, the *Hudson*, *Mitchell*, *Liberator* and the B-17 *Flying Fortress* and the *Catalina* flying boat were destined to play important military roles.

On the research front, both Britain and the United States experimented with low-drag wing sections, achieved by extending the area of the wing over which the boundary layer flow is laminar. As speeds of flight increased in aerial combat, both countries' aircraft began to run into "compressibility" troubles as they approached the so-called "sound barrier." Wind tunnel and flight research was undertaken to explore this problem and gradually there emerged a better understanding of the changing air flow phenomena in this regime of flight. When World War II, was over, it was discovered that Professor Busemann in Germany had a partial solution for this problem—sweep back of the wing. In fact, he had pointed out its possibilities in this regard at a Congress in Italy in 1935.

Canada, the World War II Period

Britain looked to the Canadian aircraft industry not for development but for production. She also looked to Canada for trained manpower and this was produced through the British Commonwealth Air Training Plan which provided the RCAF with its major role in Canada. These roles resulted in a negligible demand from industry for aeronautical research but a very considerable continuing demand from the RCAF which encountered innumerable problems with aircraft and equipments subjected to the

stress of intensive year-round training operations. As in the past, the tasks were mostly of an *ad hoc* nature not calling for "in depth" research programs.

The conduct of the two roles of production and training was outstanding. About 10 aircraft plants built over 17 000 airframes, more per capita than in any other allied country. Over 12 major types of aircraft were produced but of these, only the *Norseman* was of Canadian design. It is also noteworthy that no arrangements were made to produce any aero-engines in Canada; all were imported. From the Air Training Plan, 130 000 aircrew graduated and of these more than 80 per cent were Canadians.

On the recommendation of the RCAF, the National Research Council commenced gas turbine research in Canada with a low temperature test station established late in 1943 at Winnipeg. In 1944 a Crown Corporation, Turbo Research Limited, was created to continue the experimental work and to engage in the development of gas turbines. This came under private ownership in 1946, later becoming Orenda Engines Limited, which developed the *Chinook*, *Orenda* and *Iroquois* engines.

Following the lead given by the United States and Britain, the RCAF entered the field of aviation medicine research and development and made a number of very important contributions. A liquid oxygen system to replace the gaseous system used on long-range aircraft was developed. An oxygen "demand" valve, which conserved oxygen, supplying it only during the demand portion of the breathing cycle, was also developed. An oxygen mask to meet RCAF requirements was another item produced from this work. A human centrifuge was built in Toronto for the study of accelerations on pilots. Using this machine, an anti-g suit was developed to minimize these effects during high-g manoeuvres. Other contributions were made in the development of protective clothing and the study of night vision, cockpit lighting, decompression sickness and motion sickness.

The United Kingdom, the Post-War Period

The British aeronautical scene in the early post-war years was dominated by the gas turbine and every effort was made to accelerate its development and capitalize on the lead which had been attained. Much was made of the basic simplicity of this power

plant, its bright future, with no obvious limit to the thrust of which it could be capable, the ease with which it could be developed, and so on. Enthusiasm was strong and, even if some of the optimism about simplicity and freedom from serious development problems was dampened by subsequent experience, the results today have fully justified the faith of the pioneers. It is necessary to add that the use of the swept wing possibly had as much to do with accelerating post-war aircraft development as the gas turbine. In any case, the combination of the two was a most powerful stimulus.

Many of the problems which have become acute today were being studied and discussed in those early post-war years in Britain. In 1946, for instance, the subject of noise and the silencing of jet engines was receiving more than casual attention. In this same year the problems of all-weather landings were being fully analysed, and yet work had been proceeding on this subject for about 20 years. Only now, in 1969, does it seem likely that this will soon become a reality in commercial aviation. With anticipation of a great growth in aviation, questions of safety and air traffic control were brought to the fore, to remain with us and to become acute from time to time, as they are today.

Feeling that the hazard in breaking the sound barrier was too great to risk a pilot's life, the British missed being first to fly at supersonic speed because they concentrated on unmanned vehicles. Their approach was more difficult and slow. So this honour went to U.S. Air Force Colonel Charles Yeager in the Bell X-1 who flew above Mach 1 on October 14, 1947. However, in 1949 the prototype of the world's first jet airliner, the D.H. *Comet* was flown. It went into service with British Overseas Airways Corporation in 1952 but was later withdrawn for modifications after a number of fatal accidents due to structural deficiency. Meanwhile, the pros and cons of commercial jet flying were under constant discussion in the United States, but no tangible action was being taken. At this time, the British government initiated a program to develop several delta wing aircraft to provide research vehicles as well as operational military aircraft of this configuration. Research programs in the establishments were aimed at providing full support for these developments. Much of this total program was seen as laying the foundation for supersonic flight (beyond Mach 1) and

scientists were even beginning to think of hypersonic flight (beyond Mach 5). It has always been typical of aeronautics that in the midst of day-to-day problems and those of the immediate future, time must be found to dream about the more distant future and indeed to initiate research programs to provide many of the answers that will be required.

The first fruits of this post-war activity now began to appear in the shape of such vintage military aircraft as the *Hunter*, the *Canberra*, the *Vulcan*, the *Victor* and the *Valiant* and, for the commercial market, the *Viscount* and the *Britannia*. One of the most important contributions of research to aviation at this time came from a lengthy study of the fatigue of aircraft structures. This study led to a better understanding of the implications of fatigue and enabled, for the first time, some assessment of what the fatigue life of specific commercial aircraft might be. It also led to a spirited discussion between British and U.S. aircraft designers about the basic philosophy of aircraft design and the importance of regular inspection and fail-safe structures.

The post-war years in Britain and the United States were the most intensive period of development in aviation history. With the wartime achievements as a base, followed by almost continuous military operations somewhere in the world, including of course the Korean War, coupled with an almost explosive growth in commercial aviation all over the world, it is not difficult to understand why this should have been so. By about 1960 military and civil aircraft had advanced in complexity and cost over the aircraft of the war period to an extent that far exceeded the comparable advance from the World War I to the World War II period. The engineering man-hours necessary in the design of aircraft had risen by several orders of magnitude. Computers had, five years or so earlier, been introduced into the design process but they have not carried enough of the design load and are only now showing promise of fulfilling expectations. Increased wing loadings resulted in much higher aircraft "densities" and new materials and production methods became mandatory. Great advances had taken place in hydraulic and electrical systems, fuel systems, powered control systems and in aircraft instruments and equipment such as automatic pilots and radio navigation and communication systems.

The size and speed of commercial aircraft had risen to the point where fewer aircraft could carry the same number of passengers over the same routes in a working day, enabling airline fleets to keep pace with the annual growth of passenger-miles flown. The cost of developing both military and civil aircraft and the price tag on the finished article, even taking into account the post-war inflation, were skyrocketing.

Military aircraft development programs would be initiated on the assumption that the costs would not escalate, yet this was seldom, if ever, the case. Such programs were aimed to produce an aircraft which when placed in service, some seven to ten years later, would be at least comparable in performance with its contemporaries, preferably better. At a time of rapid technological evolution this was a formidable challenge. Many gambles had to be taken, on the assumption that technical problems would be overcome in a timely way, that key component items such as engines, armament, avionics, which were usually under development at the same time, would be ready at the right time and would perform as initially predicted. Escalation of costs, at least to a moderate extent, was understandable. On the other hand, industry has not always done its best in costing such programs or in managing them. In such a complex environment, calling for large expenditures of public funds, those involved in both public and private sectors can get cold feet at the mere thought of failure, and to face the situation squarely, the history of aircraft development is more than sprinkled with its share of unsuccessful projects. If the domestic market was a limited one and the export market uncertain, governments have, in the face of such high costs, taken the safer course of procuring from abroad. The British government chose to do this for the first time in 1965 when it cancelled the TSR-2 apparently for the reasons just discussed.

In the case of commercial aircraft the situation is not much different. With the very high cost of development and production, not every aircraft company can afford to finance such programs. In Britain the government paid about half the cost of "launching" these new commercial aircraft but even with this incentive the risks still proved to be discouragingly high. Because the airline business has become fiercely competitive, the selection of new aircraft by the airlines, aside

from political considerations, has developed into a meticulous, highly specialized analysis. Not only must the size, speed and range of the chosen aircraft fit the airlines' traffic volume and overall route structure, but the economics must be convincing. This means that the revenue generated in relation to the direct operating costs must be superior to that of similar contemporary aircraft. Under these circumstances the business of selling aircraft, domestically and internationally, has become highly competitive also.

Since about 1955 there has been in Britain a decline in the numbers of military and civil aircraft produced. With a relatively small domestic market and a highly competitive situation in the world market, Britain has decided that its future lies with Europe and in joint development programs with European countries, as exemplified by the Anglo-French *Concorde* and *Jaguar* and the multirole combat aircraft to be developed with West Germany and Italy. Whether this course of action will stimulate or eventually stifle Britain's design and engineering genius remains to be seen. However, because the aircraft industry in all countries is a spearhead for technology in its broadest sense, Britain cannot let her traditional leadership in aeronautical innovation decay.

The United States, the Post-War Period

In the United States, as World War II drew to an end, it was clear that a dynamic and expanded program of research and development would be essential if technology was to take advantage of the higher speeds of aircraft made possible by the jet engine. In 1944 General of the Air Force, H. H. Arnold, called on Dr. Theodore von Karman, the distinguished aeronautical scientist and engineer, to create a scientific advisory board which would look 20 years into the future and would specify the steps necessary to make the U.S. Air Force the strongest in the world. The National Advisory Committee for Aeronautics set about the task of extending its facilities, particularly those concerned with high-speed aerodynamics and propulsion. As in Britain, new wind tunnels were built to investigate the air flow phenomena around wings and bodies of aircraft destined to fly at transonic and supersonic speeds. The Lewis Research Center at Cleveland, like the National Gas Turbine Establishment in Britain, was created to supply basic research information to supplement the test and de-

velopment efforts undertaken by the engine companies.

In a joint program of far-reaching importance undertaken with the USAF and industry, NACA began to explore the unknown regions of supersonic and hypersonic flight. During the more than 20 years spanned by this program, a series of rocket-motor propelled manned aircraft were launched from high flying bomber aircraft and were flown to great heights and speeds before fuel exhaustion necessitated a long glide and landing. This work was conducted at Muroc in the Mojave Desert, where Roger's dry lake provides a large natural landing surface. The series of aircraft included the Bell X-1, the Douglas D-558 *Skystreak*, the Douglas *Skyrocket*, the Douglas X-3, the Northrop X-4, the Bell X-5 with variable sweep-back wing and the North American X-15. A vast amount of information concerned with stability and control, manoeuvrability, aerodynamic drag, kinetic heating, physiological questions, and so on, was accumulated in this ambitious program which was concluded after flight to 354 200 feet and 4 534 m.p.h. (Mach 6.72) had been accomplished by the X-15.

High performance military aircraft were developed for the U.S. Air Force and the U.S. Navy including the F-86 *Sabre* which played such an important role in the Korean War, the B-47 and B-52 bombers for Strategic Air Command and the so-called *Century Series* fighters including the F-100 *Super Sabre*, and F-101 *Voodoo*, Convair F-102 and the well-known F-104 *Starfighter*. Naval aircraft included the Douglas A-4, McDonnell F-2H *Banshee*, the Grumman F-9F *Cougar*, the LTV F-8 *Crusader* and A-7 *Corsair* and the McDonnell F-4 *Phantom* also adopted by the USAF.

During these post-war years the helicopter was subjected to intensive development and many different types were produced by Sikorsky, Bell, Piasecki, Hiller, Kaman, Boeing and Lockheed. This type of aircraft had proved its value in special applications where vertical or near vertical take-off and landing and vertical load lifting were required. It has proved itself also in a battlefield role in the Korean and Vietnam conflicts.

Commercial aviation in the United States surged ahead as the war ended. Passenger traffic increased about 20 per cent each year and has never ceased to climb. The aircraft companies were deluged with orders and as

these were filled, and the competition intensified, design and development efforts were increased to produce larger, faster, and more economical aircraft, appealing both to the public and the airlines. The DC-4 of 1939 gave place to the DC-6 in 1946 and in 1953 the DC-7 arrived, which had twice the power of the DC-4 and carried twice as many passengers at nearly twice the speed. But this performance was eclipsed in turn when the DC-8 and the Boeing 707 jet transports were introduced in the 1960s. The seemingly unlimited thrust potential of the jet engine not only permitted the development of the *Concorde* supersonic transport aircraft but has released the aircraft designer from the previous constraints on aircraft size imposed by the limited power of piston engines. As a result we have seen the arrival of the 775 000 lb. Boeing *Superjet* which might carry as many as 500 passengers and assessments are now being made of the social impact of the supersonic and the "jumbo" aircraft and the problems they raise for airport development and the integration of air and surface transport.

Equally dramatic has been the increase in private and business aviation, with a handful of companies producing thousands of models which have grown in performance and popularity to capture a worldwide market. Mention must also be made of the important developments in avionics which have led to multimillion dollar industries to supply the ground and airborne electronic equipment for domestic and worldwide navigation and communication systems, instrument landing systems, simulators for crew training purposes and so on.

In October 1957, Russia launched Sputnik I and the United States moved quickly in its response to the challenge of space. In July, 1958, the National Aeronautics and Space Administration (NASA) was created, using the NACA staff and establishments as the nucleus. So great was the task NASA faced, with President Kennedy's promise to land men on the moon within a decade, that aeronautical research began to take a back seat and for a number of years "space" has dominated the national scene. But Cold War and Vietnam demands in the military sphere and the vitality of commercial and civil aviation, generally, have halted the decline and brought a reappraisal in the light of national aims. As a result there has been a resurgence of emphasis on aero-

nautical research and development and a better balance has been struck. This was especially necessary because the burden of the U.S. space program has been borne not only by NASA, which was largely built on NACA, but by the member companies of the U.S. aircraft industry.

Canada, the Post-War Period

The situation in Canada after World War II was vastly different from what it had been just before the war. There was a new mood of maturity in the country based on our industrial accomplishments, the high reputation earned by our Armed Services, a general satisfaction with our overall war effort and the astonishing growth and demonstrated excellence of Trans-Canada Air Lines. The Honourable C. D. Howe, architect of so much of this success, was there to continue his guidance and leadership under which post-war plans were quick to materialize. Victory Aircraft, the Crown-owned plant at Malton, which had built Lancaster bombers during the war, was sold to Hawker Siddeley of the U.K. and became A. V. Roe Canada Ltd. In 1946 it was awarded a contract for two prototype all-weather interceptor aircraft. Canada had taken the step which was to lead to designing and manufacturing its own military aircraft. The A. V. Roe CF-100 interceptor made its first flight in 1950 and delivery to the RCAF of production aircraft, with *Orenda* engines, began the following year.

The de Havilland Company returned to the civil field not as a constructor of parent company designs but to the manufacture of aircraft designed by its own team of engineers. Its first product, the DHC-1 *Chipmunk* trainer, appeared in 1946 and was an instant success. The next year the DHC-2 *Beaver*, a rugged aircraft designed primarily for bush operations, appeared and it too was highly successful and was sold all over the world. Not the least important customer was the U.S. Army. The Fairchild Company at Longueuil also returned to the bush aircraft field, designing the *Huskie*, which appeared about the same time as the *Beaver*. It too was a good aircraft but enjoyed a limited success before the company went out of business.

A more ambitious project in the civil field was the C-102 *Jetliner* developed by A. V. Roe which flew in August, 1949, just two weeks after the *Comet* made its first flight

in the United Kingdom. This aircraft had been designed around two Rolls Royce *Avon* engines and when these were not available, a design change substituting four Rolls Royce *Derwent* engines became necessary. The new power plants increased the interference drag and the aircraft would no longer meet its design mission. Suitable facilities for investigating this problem were not available. Additionally, the company was faced with a number of mandatory changes in the aircraft to comply with certificate of airworthiness requirements. An extensive market for the C-102 had not developed and progress with the development of the CF-100 fighter necessitated all the energies the company could muster. In the face of this combination of problems, the decision was made to shelve the project.

Canadair in Montreal entered the post-war era on a wave of production orders, and it was not long in establishing its pre-eminent capabilities for production, including in most cases re-engineering of the aircraft for one purpose or another. First there were the *North Stars*, a modified version of the DC-4 with *Merlin* engines built for TCA and a considerable number of PBV *Canso* amphibians for the civil market. These were followed, beginning in 1949, by F-86 *Sabre* aircraft with *Orenda* engines, for the RCAF, West Germany, and the USAF. This requirement emanated from Canada's commitment to NATO and additionally the Korean losses sustained by the USAF.

In 1951, after the outbreak of the Korean War, the need was felt for a Canadian capability to respond quickly to military emergencies. A new Department of Defence Production was established, with C.D. Howe as its Minister, and plans were implemented to broaden our defence industrial base and especially to encourage new industries in the accessory field to support our major aircraft companies. The CF-100 was in production at A. V. Roe Canada Ltd. for the RCAF and the Belgian Air Force and T-33 jet trainers were being built under licence at Canadair.

Among the numerous characteristics of the D.H. *Beaver* that endeared it to the bush operators, lively take-off and good approach behaviour, which enabled it to operate from restricted areas, were important. In their next venture, the *Otter*—which was a somewhat larger single-engined aircraft, first flown in 1953—D.H. Canada attempted,

with success, to enhance still further this STOL (short take-off and landing) feature.

At this time, with work in progress on the USAF's first supersonic fighter (F-102), it was realized that the three-year-old CF-100 was obsolescent. The RCAF issued to A. V. Roe a specification for a two-seat, supersonic, all-weather interceptor to replace it, calling for prototype delivery in 1957. While A. V. Roe were engaged in this program, another project was underway at Canadair, to provide the RCAF with a long-range anti-submarine reconnaissance aircraft, the *Argus*. Although this was based on the Bristol *Britannia* airframe, so many changes were involved that it represented a major redesign effort. The first flight of the *Argus* took place in 1957 and it continues to carry out its maritime-reconnaissance role 12 years later. The CF-105 *Arrow*, supersonic interceptor, was to be powered by two *Iroquois* jet engines designed by Orenda Engines Limited and a new fire control system was also under development for it. It was a large and ambitious project. To expedite its development testing, a number of aircraft, built from production tooling rather than from prototype jigs, were to be used. Had the aircraft gone into production this would have resulted in an overall cost saving. As it was, the costs were soaring yet the market was restricted to domestic needs since a major effort to interest the USAF in procurement failed. The aircraft made its first flight in May, 1958, and reached a speed in excess of 1 000 m.p.h. Its fate hung in the balance for nine months while the pros and cons for continuing the program were examined. Finally in February, 1959, the government decided to cancel it. Because of the magnitude of the project and its ramifications throughout the entire aircraft industry, its cancellation had a most adverse effect. In less than 15 years our post-war policy to be self-sufficient in military aircraft design and development had ended.

With the loss of the *Arrow*, A. V. Roe Canada went out of business and altogether some 15 000 people lost their jobs. Canada lost the only military aircraft design team we ever had, many of our best engineers leaving for the more resilient design environment of the United States. Unfortunately, no steps were taken to salvage any technical knowledge or experience from this program and the only lessons we learned were economic ones.

Canadair continued its production of *Argus* aircraft and developed a swing-tail version of its CL-44 (*Yukon*) transport aircraft (also based on the *Britannia* airframe). This aircraft, while achieving only limited sales to the air-freight carriers has proved to have attractive operating costs. De Havilland, meanwhile, was continuing its highly successful output of unusual aircraft. The DHC-4 *Caribou*, a twin-engined transport, appeared in 1953 and again demonstrated outstanding rough-field adaptability coupled with excellent STOL and load-carrying characteristics. The U.S. Army, again, was an enthusiastic customer. Within the last five or six years the company has switched to turbine-powered aircraft, all in the STOL field. First came the *Buffalo* as a successor to the *Caribou*, followed by the *Turbo-Beaver* and the *Twin Otter*. This last aircraft has rapidly achieved worldwide popularity as a STOL transport and has won a good export market. Like the *Turbo-Beaver*, the *Twin Otter* is powered by United Aircraft of Canada's PT-6 gas turbine.

In 1960 Canadair received a contract for the manufacture under licence of the Lockheed CF-104 *Starfighter* for the RCAF's strike-reconnaissance role in Europe. The company has had, over the years, a team of competent engineers to cope with the many and varied redesign tasks inherent in most of their production contracts. This team had yearned to turn its talents to the design of a complete aircraft and in due course this became possible. A jet trainer aircraft (CL-41) was designed as a private venture and in 1962 was adopted by the RCAF. In 1966 the company designed and developed the CL-84 tilt-wing, vertical or short take-off and landing (v/STOL) aircraft, which is still under evaluation by the Canadian Forces. In 1959 the company began the development of a reconnaissance drone. This private venture (CL-89) ultimately received international support and is now in production for Canada, the United Kingdom and the Federal Republic of Germany. A fourth project, completed recently (1968), has been the development of the CL-215 twin-engined water bomber, an amphibian designed primarily for forest and bush fire fighting but adaptable to other basic utility-transport roles. The company is now engaged in producing a Canadian modified version of the Northrop F-5 aircraft for the Canadian Armed Forces and the Royal Netherlands Air Force. In a review of our

major manufacturers of aircraft, mention must also be made of Douglas Aircraft of Canada, which was established recently as a subsidiary of McDonnell-Douglas Corporation to build major airframe components for the DC-9 and DC-10 jet transport aircraft. This company has had a rapid build-up to become a most significant factor within our aviation industry.

Orenda Engines Limited survived the cancellation of its *Iroquois* project largely on production orders for the G.E. J-79 engines for the CF-104, and J-85 engines for the CL-41. United Aircraft of Canada began the design and development of small turbine engines in 1958. Its most famous power-plant family, the PT-6 series propeller turbine in the 600 h.p. class, has been selected by innumerable, worldwide aircraft manufacturers to power their aircraft. The latest development venture of the company is the JT15D turbo-fan engine, in the 2 000 lb. thrust class.

Reflecting post-war events in Britain and the United States, Canada experienced a strong industrial expansion in the field of aviation electronics (avionics) and a number of companies have built up an excellent record of accomplishments in this field. It is the story of de Havilland repeated; created to meet a domestic requirement, the companies have expanded their business to cater to a large and growing export market. To mention only a few of the dozen or so companies, Canadian Aviation Electronics has gained international recognition for its flight-training simulators; Collins Radio is known for its airborne radio communication and navigation equipment; Garrett Manufacturing is active in air data computers; Philips makes aeronautical beacon equipment; Computing Devices of Canada produces air navigation, anti-submarine warfare, and display equipments; Aviation Electric makes fuel control systems, aircraft and missile instrumentation, gyros and servo amplifiers; Litton Systems (Canada) Limited produces and markets inertial navigation systems, tactical display systems, special purpose airborne computers and automatic test equipment; Canadian Marconi is well known for its airborne doppler navigation system and radio altimeters; Raytheon is in the air traffic control navigation aids business; and Ferranti-Packard and Smiths are suppliers of aircraft instruments. The wide range of avionic equipments produced by these companies represents both native and imported technology.

Some advanced technology items are based on Canadian forethought and ingenuity; in the case of imported technology, Canadian talent has been able to add to the quality or reliability by engineering or production improvements, just as Canadair does in its aircraft production programs.

The tremendous growth of commercial aviation in Canada since the war is a story in itself. We have seen the steady evolution of our main carriers, Air Canada and CP Air, to the point where they are two of the most highly regarded international airlines in the world. Air Canada ranked seventh in size in 1968 and as the nationally owned airline, had carried the flag from transcontinental operations, across the Atlantic to Europe, and down to the Caribbean islands and Florida by 1950. It has had a flair for careful selection of equipment and in 1963 became the first airline in the world to operate an all-turbine fleet of aircraft. Its annual revenue is now running at \$387.6 million (based on 1968 business of over 5.616 billion revenue passenger-miles flown) representing an average increase since the war of nearly \$17 million per annum. The company has over 16 500 employees and its operations are conducted with 109 aircraft.

CP Air operates over an unduplicated route mileage (domestic and overseas) of 86 881 (Air Canada's is 78 820). Its rise to prominence began in 1949 when it was awarded trans-Pacific routes to Australia and Japan. The Korean War and DEW line construction provided important air transport business for the airline, which greatly assisted in its development. The global planning of its overseas routes by management has been particularly imaginative and astute, from which might be expected a more rapid increase of traffic than that perennially enjoyed by the airlines. The operating revenue of CP Air in 1968 was \$106.7 million based on 1.7 billion revenue passenger-miles flown. The company employment is 4 410 and its total equipment at December 31, 1968, amounted to 23 aircraft.

Canada has, also, a number of large regional air carriers, Nordair, Pacific Western Airlines, Quebecair, Trans Air Limited and Eastern Provincial Airways (1963) Limited. Mention must also be made of the several hundred charter operators and local carriers who continue to provide an important service in all parts of Canada. The good work begun by the bush pilots in the 1920s has been con-

tinued and extended by the generation of pilots which followed them. Ten years after World War II, aircraft were being used all over the world in agriculture, pest control, aeromagnetic survey and exploration, geology and forest appraisal. In an address to the Royal Aeronautical Society in December, 1954, HRH Prince Philip said, "Canada has led in the development of the technique of assessing the composition, wealth and best logging plan for her vast forests, using stereo-examination of photographs combined with ground work." Canada has indeed pioneered in the use of aircraft for many varied roles and the imagination and resourcefulness of Canadians will no doubt uncover still more possibilities as time passes and the tasks to be done proliferate in both number and character.

Soon after the war, the University of Toronto established both undergraduate and postgraduate training in aeronautical subjects. The undergraduate courses were given as the "aeronautics option" in engineering physics while the postgraduate studies and research facilities were provided in a new organization, the University of Toronto Institute of Aerophysics (now the Institute for Aerospace Studies), with Dr. G. N. Patterson as its Director. The Institute was assisted in its early years by funds from the Canadian government (Defence Research Board). It was a success from its earliest days and has grown steadily in size, competence, and reputation. Its initial emphasis was on training of scientists for research and development in the basic physics of gases, applied aerodynamics and ballistics, with special emphasis on supersonic flight. It trained its graduate students to the M.Sc. and Ph.D. level. Besides support from the Canadian government (the National Research Council and Defence Research Board), it received financial assistance from U.S. agencies in the form of research grants. Over the years it has slowly extended its interests to include such subjects as rarefied gas flow, blast phenomena, spacecraft orbital mechanics, acoustics, wind loads on buildings, and so on.

In 1949 McGill University established a Gas Dynamics Laboratory under Mr. D. L. Mordell to train engineers to the M.Eng. and Ph.D. level and to conduct applied research and development work in a search for interesting research problems. The laboratory was slow in developing, perhaps because its mission was not sufficiently clear and tended

in any case to be too close to development to suit a university environment. Eventually, however, the university commenced research work on hypersonic combustion and began to pioneer in this field of study which has relevance to the regime of flight beyond the supersonic. It has had financial support from the Canadian government and from U.S. agencies as well. Recently an excellent research program under Professor B. G. Newman has developed in basic fluid mechanics. This has included studies of turbulent flow in pipes and turbulent boundary layers. Newman and his students have made important contributions in explaining the mechanism of flow in the boundary layer, particularly as regards the stability of the flow in the presence of adverse pressure gradients and with wall jets. Of immediate practical interest also is their work on propellers at zero advance. A number of other universities have also engaged in various aeronautical research studies usually built around the specific interests and capabilities of individual professors and on a much more limited scale than that sustained by the University of Toronto.

At the end of the war the tendency within the staff of the National Research Council aeronautical laboratories was to turn from *ad hoc* problem solving to fundamental research. This was, in fact, a common reaction throughout the other divisions of NRC. This policy was encouraged, although it was agreed that industry would continue to be assisted where possible. As in Britain and the United States, it was recognized that the gas turbine development would need the support of fundamental research and NRC took steps to expand its facilities in gas dynamics and in high-speed aerodynamics. To assist industry in its new aircraft development programs, NRC also undertook an expansion of its structures laboratory to permit tests on full-size wings and on structural components. One of the most important areas of post-war growth was the acquisition of a flight test and flight research activity, under the control of the NRC, but operated with RCAF participation. A low temperature laboratory was also added wherein the control which can be exercised over the conditions represented a great improvement over winter field tests. Considerable modernization of the facilities in the low speed and high speed aerodynamic laboratories has taken place to improve their utility or to extend their range of operation. Mention should also be

made of the large new facilities which have been added in recent years. These include the 10 ft. by 20 ft. VTOL engine testing tunnel built in 1962-63; the 5 ft. by 5 ft. trisonic tunnel completed in 1962, and the 30 ft. VTOL tunnel which is now nearing completion, all intended for the support of industrial developments.

The Associate Committee on Aeronautical Research which had existed since 1920, and its technical subcommittees, were permitted to lapse in 1948, apparently without any disturbing effect on operations or programs of the laboratories. In 1947 the Defence Research Board was created by Parliament as an integral part of the Department of National Defence, to be responsible for the application of science to defence matters. It had no desire to duplicate the aeronautical facilities of the NRC but, as in other areas, proposed to utilize existing establishments for the conduct of desired programs. Some of the recent successful aeronautical development programs in Canadian industry owe much to the support given them by DRB through its contracts and the Defence Industrial Research Program. These include: the Canadair CL-84 tilt-wing v/STOL project; STOL aircraft developments at de Havilland, including the work on the augmentor wing; and the research and development work which led to the United Aircraft of Canada PT-6 engine.

With the outbreak of the Korean War and the resulting increase in military funding, a much expanded effort in aeronautical research and development was anticipated. The view was still current in those days that aeronautical research was justifiable mainly, if not only, on defence grounds. Since the funds for expanded facilities would have to come from the DRB portion of the defence vote (NRC's budget could not be stretched to cover such an expansion) the argument was advanced that the Defence Research Board should assume control of the aeronautical laboratories and fund their expansion. This thesis was accepted but some doubts remained about the position of civil aviation and its need for access to research facilities. It was finally agreed that the requirements of civil aviation could be met without difficulty and in order to facilitate the transition of the laboratories from NRC to DRB control, an interdepartmental policy committee organization was recommended, at least on an interim basis. A new name, the National Aeronautical Establishment (NAE), was to be

given to the laboratories. The National Research Council was to retain administrative responsibility for NAE but the broad policy regarding its functioning was to be formulated by the National Aeronautical Research Committee (NARC) consisting of the President, NRC; the Chairman, DRB; the Chief of the Air Staff, RCAF; and the Deputy Minister, Department of Transport. Later, the Deputy Minister, Department of Defence Production was added. The chairmanship of NARC was to be on a rotating basis among the members. A Technical Advisory Panel (TAP) to advise the NARC and the Director, NAE, on aeronautical scientific and technical matters involving policy was also recommended in this new organization. The Cabinet approved these recommendations in December, 1950.

These new interdepartmental operations got underway in 1951 and arrangements were put in hand to provide the desired expansion of facilities, most of which have been referred to earlier in this review. In particular, the Flight Research Section was moved to a new site at Uplands Airport where space was also provided for the major expansion of facilities. The Technical Advisory Panel was active initially, but from 1954 to 1958 it held no meetings. In 1954 NARC had given TAP approval to establish technical subcommittees but action was not taken on this until 1960-61 when three associate committees (structures and materials, aerodynamics, propulsion) were approved by NRC. A fourth associate committee, on avionics, was added in 1964. These committees were representative of government, university and industry. In 1958 NARC concurred in a decision to abandon the original proposal to transfer to DRB the jurisdiction over all or part of the aeronautical laboratories.

In the 19 years since the NARC-TAP organization had been created, great changes have taken place in both military and civil aviation, in the aircraft and allied industries, in the position of research and in government policies and legislation bearing on all these aspects.

Both the NARC and the TAP had from time to time questioned their own duties and roles. In 1963, for instance, revised terms of reference had been accepted for both committees but these did not resolve the basic problems.

The recommendations of the associate committees achieved action most frequently by direct response on the part of the NRC

representatives subject only to financial limitations. The channel through the TAP and NARC committees was extremely slow and the constitution of NARC such that it could provide no effective support for aeronautical research and development. While the organization might deal in a limited way with existing problems, it was recognized that some changes in machinery and organization would probably be necessary, depending in large part on the overall policy for aeronautical research and development from the point of view of national interests and programs. It was against this background of prolonged uncertainty that the National Aeronautical Research Committee requested the Science Council to undertake this study.

Appendix 2

Membership of the Study Committee

Chairman

J. J. Green
Director of Government Relations
Litton Systems (Canada) Ltd.
Ottawa, Ontario

Members

J. T. Dymant
Vice President
R. Dixon Speas Associates Ltd.
Montreal, Quebec

A. J. R. Smith*
Chairman
Economic Council of Canada
Ottawa, Ontario

Advisers

H. C. Douglas
Director
Office of Science and Technology
Dept. of Industry, Trade & Commerce
Ottawa, Ontario

R. D. Hiscocks
Vice President (Scientific)
National Research Council
Ottawa, Ontario

W. M. McLeish
Chief, Aeronautical Engineering Div.
Department of Transport
Ottawa, Ontario

G. N. Patterson
Director
University of Toronto Institute for
Aerospace Studies
Toronto, Ontario

G. T. Rayner
Director, Economic & Scientific
Programs Division
Treasury Board
Ottawa, Ontario

R. D. Richmond
Vice President and General Manager
Douglas Aircraft of Canada Ltd.
Malton, Ontario

D. R. Taylor
President
Aviation Electric Ltd.
Montreal, Quebec

K. F. Tupper
Vice President (Administration)
National Research Council
Ottawa, Ontario

R. F. Wilkinson
Director-General
Defence Research Establishment Ottawa
Shirley Bay, Ottawa, Ontario

Science Council Staff

A. H. Wilson, *Project Officer*
J. Mullin, *Secretary*

*A.J.R. Smith was assisted by D. W. Henderson of the staff of the Economic Council of Canada.

Note: At the time of their appointment to the Committee, *Dr. Green* was Director of Research of Litton Systems (Canada) Ltd.; *Mr. Dymant* was Chief Engineer of Air Canada; *Mr. Hiscocks* was Director of Future Projects and Research in the Aircraft Division of The de Havilland Aircraft of Canada Ltd.; *Mr. Richmond* was Vice President of United Aircraft of Canada Ltd.; *Dr. Tupper* was a Vice President (Scientific) of NRC; and *Mr. Wilkinson* was Scientific Assistant to the Chief of Technical Services of the Department of National Defence.

Appendix 3

Definitions

The definitions of research, development, etc., adopted for the purposes of this report are those given on page 7 of the Science Council's Report No. 4, *Towards a National Science Policy for Canada*; October, 1968, as follows:

(1) *Basic or Fundamental Research* which is a generalized search for new knowledge without specific application in mind, and which is one of man's crowning cultural achievements. Any piece of basic research is judged on the contributions which it makes to the conceptual development of science.

(2) *Applied Research* is the search for new knowledge to provide a solution to a specific problem which is defined at the outset of the research program. It does not differ radically from basic research in methods or scope, but in motivation. Applied research programs must be judged by their relevance to the pre-selected objective.

(3) *Development* is really a final stage of applied research which is most clearly seen in the evolution of new goods or services. It is a costly activity in as much as the building of prototypes, the construction of pilot-plants or the conduct of full-scale trials are costly undertakings.

(4) *Innovation* is the practical implementation of the results of research and development to provide new or improved goods or services. Innovation is often a capital-intensive activity since new production facilities are often required. In deciding to undertake programs of development and innovation, the expenditures foreseen must be weighed against the probability of achieving economic gain or social benefit.

Appendix 4

Contacts with Associations and Individuals

List of Meetings and Visits

The following associations responded to the Study Committee's invitation to present views regarding aeronautical R & D activities in Canada:

Air Industries Association of Canada
(Mr. D. A. Golden, President)

Air Transport Association of Canada
(Mr. A. C. Morrison, President)

Alberta Aviation Council
(Mr. F. G. Winters, General Manager;
Dr. W. B. Hansen, Chairman, Aviation
Medicine Committee;
Mr. A. W. Holmes, Chairman, Aviation
Education Council)

Canadian Aeronautics and Space Institute
(Mr. H. C. Luttman, Secretary)

Canadian Aircraft Maintenance Engineers
Association
(Mr. P. F. Rider)

Canadian Air Line Pilots Association
(Mr. R. M. Kidd, Director, Technical and
Air Safety Division)

Canadian Air Traffic Control Association
(Mr. G. J. Williams, Managing Director)

Canadian Business Aircraft Association Inc.
(Mr. J. E. Peacock, Executive Director)

Canadian Owners and Pilots Association
(Mr. W. N. Peppler, Manager)

Electronic Industries Association
(Mr. Cowan Harris, General Manager)

Saskatchewan Flying Farmers
(Mr. D. V. Hunt, President)

Royal Canadian Flying Clubs Association
(Mr. R. P. Purves, President)

Submissions were received from the following individuals:

Mr. Norman D. P. Brossard
(12761 Camirand Street, Pierrefonds, Quebec)
Mr. Donald M. Fawler
(319 First Avenue, Brockville, Ontario)
Mr. Norman Gardner
(1577 Prince of Wales Drive, Ottawa)
Mr. C. R. Gollihar
(Vice President, Douglas Aircraft Company of Canada Ltd., Malton, Ontario)
Mr. K. Irbitis
(12007 Lachapelle Street, Montreal, Quebec)
Mr. P. Kaphalakos
(104 Carsbrooke Road, Etobicoke, Ontario)
M. Louis-Philippe Lagacé
(Desjardins Mutual Life, 2506 Triquet, Ste-Foy, Quebec)
Mr. G. R. Stout
(639 Thistle Crescent, Fort William, Ontario)

A submission was also received from the Technical Advisory Panel of the National Aeronautical Research Committee (Mr. W. M. McLeish, Chairman).

List of meetings and visits:

Air Industries Association of Canada.
Canadian Air Line Pilots Association
(Mr. R. M. Kidd).
Saskatchewan Flying Farmers
(Mr. D. V. Hunt).

National Aeronautical Establishment and Division of Mechanical Engineering, National Research Council, Ottawa.
Canadair Limited, Montreal, Quebec.
The de Havilland Aircraft of Canada Limited, Downsview, Ontario.
United Aircraft of Canada Limited, Longueuil, Quebec.
Douglas Aircraft Company of Canada Limited, Malton, Ontario.
Defence Research Establishment Toronto, Downsview, Ontario.
Institute for Environmental Medicine, Toronto, Ontario.
Dept. of Mechanical Engineering, McGill University, Montreal.
Aviation Medical Research Unit, McGill University, Montreal.
Canadian Transport Commission, Ottawa.
Dr. H. Guyford Stever, Chairman, Aeronautics & Space Engineering Board (ASEB). National Academy of Engineering, Washington, D.C.
Dr. R. L. Bisplinghoff, Vice Chairman, ASEB.
Col. R. J. Burger and Col. J. R. Fowler of the Secretariat of the ASEB.
Sir Morien Morgan, Controller, Guided Weapons & Electronics, Ministry of Technology, London, England.
Sir George Edwards, Managing Director, British Aircraft Corporation, Weybridge, England.
Professor D. Keith-Lucas, President, Royal Aeronautical Society, London, England.
Professor A. R. Collar, formerly Chairman, Aeronautical Research Council, London, England.
Mr. L. F. Nicholson, Chief Scientist (Royal Air Force), Ministry of Defence, London, England.
Mr. Handel Davies, Deputy Controller Air (R & D), Ministry of Technology, London, England.

Appendix 5

List of Principal Canadian Manufacturers of Accessories, Equipment and Avionics for Aircraft and Ground Support Use

*Abex Industries of Canada Limited,
Montreal, Que.*

Landing gear, hydraulic pumps and motors, flight control servo valves, and structural components for a wide range of aircraft built in Canada and the U.S.A.

Aeroquip (Canada) Limited, Toronto, Ont.

A wide line of hydraulic hose, fittings, couplings, seals and flanges.

Aviation Electric Limited, Montreal, Que.

Gas turbine fuel control systems, aircraft instruments, ground support test equipment, navigation devices. Canada's largest R & O contractor for aircraft instruments and accessories.

Bowmar Canada Limited, Ottawa, Ont.

Servo motors, servo amplifiers, digital indicators, stepping motors, rotary and stepping switches, resolvers and servo systems.

Bristol Aerospace Limited, Winnipeg, Man.

Gas turbine hot-end components, JATO installations, large repair and overhaul depot for aircraft, motors and accessories. Rocket motors and components.

CAE Industries Limited, Montreal, Que.

Flight simulators, trainers, data-processing and display systems, communications and navigation equipment. Electronic repair and overhaul facility.

*Canadian General Electric Co. Ltd.,
Toronto, Ont.*

Aircraft and ground-based communication systems, airborne and ground radar systems, air traffic control aids.

Canadian Marconi Company, Montreal, Que.
Aeronautical electronic equipment, Doppler sensors, navigation computers, radar altimeters.

Canadian Westinghouse Company, Hamilton, Ont.

Data transmission equipment, computers, data-processing equipment, airborne and ground radar systems, ground-based aircraft radar tester.

Collins Radio Company, Toronto, Ont.

Airborne and ground-based communication systems, navigation and flight control equipment.

Computing Devices of Canada, Ottawa, Ont.

Airborne digital computers, head-up, moving map, tactical and horizontal display systems, position and homing indicator, ANTAC navigation system.

Dowty Equipment of Canada Ltd., Ajax, Ont.

Aircraft landing gear, hydraulic equipment and fuel system components. Repair and overhaul facility.

Fairey Canada Limited, Dartmouth, N.S.

Spare parts, hydraulic components and accessories for airframes, "Beartrap" helicopter haul-down and securing system, repair, overhaul and conversion of aircraft.

Ferranti-Packard Limited, Toronto, Ont.

Data transmission systems, special purpose computers, data-processing equipment.

Garrett Manufacturing Limited, Rexdale, Ont.

Airborne static inverters, pneumatic signal generators, power supplies, regulators, servo systems, distress beacons, airborne temperature controllers.

Heroux Limited, Longueuil, Que.

Aircraft landing gear and hydraulics; large subcontract facility for aircraft components and assemblies. Repair and overhaul facility for hydraulics.

Leigh Instruments Limited, Carleton Place, Ont.
(excluding subsidiaries)

Servo amplifiers, servo pneumatic altimeters, radar altimeters, avionic instruments, crash position indicators, emergency beacons, flight data recorders, special computers.

Litton Systems (Canada) Ltd., Rexdale, Ont.

Inertial navigation systems, special purpose computers, data-processing equipment, servo systems, weapons release computers and ground support equipment. Repair and overhaul facilities.

Lucas-Rotax Limited, Montreal, Que.

Fuel systems and valves for gas turbine engines, hydraulic equipment for aircraft and missiles. Repair and overhaul facility.

Philips Electronics Industries Ltd., Toronto, Ont.

Airport traffic control communication systems. Radar and radio range ground transmitters.

RCA Limited, Montreal, Que.

Airborne and ground-based communication systems, satellite communication, special purpose computers, airborne and ground-based radar systems.

Raytheon Canada Limited, Waterloo, Ont.

Special purpose computers, data-processing equipment, navigation equipment, airborne and ground-based radar systems.

Uniroyal Ltd., Aircraft Products Division, Montreal, Que.

Aircraft and helicopter self-sealing fuel cells for a wide range of American aircraft.

Appendix 6

DND Air Operations, 1968-69				
Operation	Personnel	Costs		
	Military /Civilian	Personnel	Other	Total
	number	\$000's	\$000's	\$000's
Air Strike /Reconnaissance	4 301	40 096	27 547	67 643
Air Defence	6 921	54 573	28 333	82 906
Tactical Air	1 748	17 897	9 514	27 411
Maritime Warfare (Air)	6 044	64 280	40 942	105 222
Airlift	8 825	67 811	24 179	91 990
Flying Training	5 106	41 231	15 339	56 570
Air Repair & Maintenance		5 376	357	5 733
Air Search and Rescue	318	2 799	2 335	5 134
Total	33 263	294 063	148 546	442 609

Appendix 7

Inventory of DND Aircraft

Type	Total Available to DND*	Operational
<i>Jet:</i>		
T-33	213	158
CF-104	183	†
CF-101B	60	†
CF-100	43	†
Falcon	7	7
Tutor	179	116
CF-5	10	†
<i>Propeller:</i>		
Dakota C-47	76	63
L-19	24	24
Argus	32	†
Tracker CS2F	69	†
Caribou	8	8
Otter	38	33
Chipmunk	51	30
Expeditor C-45	53	43
Albatross	9	9
<i>Turbo-Prop:</i>		
Buffalo	15	12
Yukon	12	12
C-130	23	23
Cosmopolitan	9	7
<i>Helicopter:</i>		
CH112	20	20
CH113	15	16
CUH-1H	10	4
H21	6	6
CHSS-2	38	23
HO4S	5	5
H34	3	3
H44	4	2

*As quoted in Hansard 26 February 1969, for "number of aircraft employed by the Armed Forces".

†Not available in unclassified form.

Appendix 8

Capital Plant for Aeronautical R & D Owned and Operated by the National Research Council

The following is a description of the major installations, facilities and equipment of total or partial significance to aeronautical research and development.

Wind Tunnels

(1) 30×30 ft. low-speed (v/STOL) wind tunnel, with external balance, data system, variable frequency power supplies, and compressed air. Speed range: 0 to 200 ft./sec.

(2) 6×9 ft. low-speed wind tunnel, with external balance, data system, variable frequency power supply, and compressed air. Speed range: 0 to 350 ft./sec.

(3) 15 ft. diameter open jet vertical tunnel, with strain gauge balance and data system. Speed range: 0 to 70 ft./sec.

(4) 3×3 ft. low-speed wind tunnel. Speed range: 0 to 200 ft./sec.

(5) 1.75×2.5 ft. low-speed wind tunnel. Speed range: 0 to 100 ft./sec.

(6) 5 ft. blowdown wind tunnel, suitable for the measurement of steady and fluctuating forces, moments, pressures, heat transfer and aeroelastic behaviour of wind tunnel models up to about $3\frac{1}{2}$ ft. span and 6 ft. long. Mach number range, with 5×5 ft. working section, 0.1 to 4.5 including complete transonic coverage, with Reynolds number per foot typically 15×10^6 and variable. For two-dimensional section testing, a special $5 \times 1\frac{1}{4}$ ft. working section enables Reynolds

number per foot to be as high as 40×10^6 in the Mach number range 0.7 to 1.1. Typical running times are 10 to 50 seconds, with a run frequency of 3 per hour. Controlled variations of model attitude, stagnation pressure and Mach number during a run. Internal strain gauge balances, pressure transducers and model manufacturing and inspection facilities available. Air supply facility for 5 ft. wind tunnel comprises 12 000 h.p. compressor set delivering 41 lbs. of dry air per second at 312 p.s.i.a. Air storage volume is 50 000 cubic feet. Auxiliary equipment can be attached to this air supply.

(7) 5 in. blowdown wind tunnel— $1/12$ scale model of 5 ft. blowdown tunnel with similar but appropriately scaled performance. Suitable for small-scale research work. Can be operated continuously off main air supply of 5 ft. tunnel.

(8) 12 in. hypersonic gun tunnel, for measurement of forces, pressures, and heat transfer on small research models at hypersonic speeds. Mach number range from 8 to 12 with stagnation conditions of $2\,000^\circ\text{K}$ and 5 000 p.s.i., giving typical Reynolds number of $3 \times 10^6/\text{ft.}$ Run durations with steady conditions are about 15 milliseconds. Oscilloscopes with Polaroid cameras for data gathering.

(9) Propulsion tunnel, which will provide air velocities over the range from 0 to 250 ft./sec. in a working section $10 \times 20 \times 40$ ft. Force balances are available and both suction and blowing air are provided for driving models of substantial power or for aerodynamic experiments requiring blowing or suction. Data collection and tape print-out equipment is available.

(10) High-speed variable density icing tunnel. This tunnel has a 1×1 ft. working section and will operate at speeds up to a Mach number of 0.9 at altitudes up to 30 000 ft. and at temperatures down to -40°C .

(11) $4\frac{1}{2} \times 4\frac{1}{2}$ ft. low-speed icing tunnel, used for simulation of icing conditions in flight. Can be refrigerated to -20°C , has a top speed of 200 m.p.h., and is equipped with an array of water atomizing nozzles. This tunnel can also be used for limited aerodynamic testing.

Water Tunnel

10 \times 13 in. flow visualization water tunnel, with accessories. Speed range: 0 to 10 ft./sec.

Computers

(1) IBM 1620, 20K memory, card read-punch

(2) An Electronic Associates 690 hybrid computing system is operated on an "open-shop" basis.

Research Aircraft

(1) Variable-stability Bell 47G3B1 helicopter, operated as an airborne v/STOL aircraft simulator (CF-PDX-X). The aircraft is capable of simulating the flying characteristics of other VTOL and STOL aircraft and of carrying out general v/STOL flying qualities research.

(2) North Star aeromagnetic research aircraft (CF-SVP-X).

(3) T-33 turbulence research aircraft (CF-SKH-X). The aircraft is equipped with a 14-channel multiplexed, FM and AM analog tape recorder. It is capable of measuring true gust velocity components and numerous other atmospheric and aerodynamic parameters.

(4) T-33 pacer and reference aircraft (CF-WIS-X). This aircraft is being equipped with basic sensing elements and a recorder for use in support of turbulence and other research requiring subsonic operation below 40 000 ft.

(5) Beech 18 general purpose and CPI range test aircraft (CF-SKJ-X).

(6) and (7) Bell 47G helicopters (CF-SCK-X and CF-SCJ-X). These two aircraft are used for the development of new instruments and equipment and for aerial photography.

(8) Harvard general purpose aircraft (CF-PTP).

Propulsion Research Facilities

(1) Air supplies. Air is available for various tests requiring it in quantities and at pressures as follows:

a) Compressor: 31.4 lb./sec. at 7 atmospheres, or 52 lb./sec. at $2\frac{1}{2}$ atmospheres, or 600 cu. ft./sec. flow (measured at the suction condition) at suction conditions down to approximately 3 p.s.i.a.

b) Exhauster: 870 c.f.s. (measured at suction pressure) at suction conditions between 4 p.s.i.a. and 1 p.s.i.a.

(2) Compressor test rig, consisting of a closed circuit tunnel with means for removing heat and including a 4 500 h.p. turbine for driving compressors or fans up to speeds of approximately 25 000 r.p.m. Instrumentation includes pressure, torque and speed measurement.

(3) Altitude tank, suitable for measuring the performance of small gas turbines having mass flows less than 5 lb./sec. at altitudes up to about 50 000 ft. Air and cell temperatures can be varied over a range from $+150^{\circ}\text{C}$ to -100°C .

Engine Test Equipment

There are three test cells and one anechoic chamber suitable for work for the aircraft industry.

(1) One cell is equipped for testing aircraft jet engines up to 30 000 lb. thrust.

(2) One cell is equipped for testing alternatively:

a) jet engines up to 30 000 lb. thrust;

b) turbo-props up to 30 000 lb. thrust;

c) icing of aircraft engines up to 30 000 lb. thrust, $25 \times 25 \times 80$ ft., complete with refrigeration capacity 15 degrees lower than ambient temperature, equipped with silencers.

(3) One test cell suitable for research on aircraft engine compressors, $15 \times 15 \times 80$ ft., complete with silencing fore and aft.

(4) The anechoic chamber, for studies of noise in lifting and thrust fans for aircraft (VTOL), approximately $20 \times 20 \times 90$ ft. There is also a jet aircraft thrust platform which has a capacity for supporting aircraft with a gross weight up to 150 000 lbs. and an engine thrust up to 100 000 lbs.

Low Temperature Research Facilities

(1) Cold box. A 5 cu. ft. top-opening box capable of attaining -80°F is used for testing small material samples.

(2) Large cold chamber. A chamber 50×15 ft. with a headroom of 14 ft. and capable of being cooled to -85°F or heated to $+160^{\circ}\text{F}$ is used for environmental testing of engineering equipment and for research investigations into low temperature problems. The refrigeration capacity of the chamber exceeds 100 tons, 1 200 000 B.T.U. per hour, at -65°F .

Instrumentation Research Equipment

(1) Environmental test chamber, $4 \times 4 \times 4$ ft., altitude capacity 70 000 ft.; temperature range -55°C to $+85^{\circ}\text{C}$; pull-down time, 2 hours.

(2) Super-clean room, $10 \times 8 \times 20$ ft. Class 250, but capable of going to Class 100.

Miscellaneous Equipment

(1) Fatigue testing equipment: thirteen fatigue testing machines of various load capacities, for testing material specimens or elementary structures.

(2) Bird impact facility.

(3) Strength testing machines.

(4) Static structure test equipment. This equipment consists of a laboratory floor reinforced with a network of channels, a large amount of structural steel for the erection of gantry frames, numerous hydraulic actuators with capacities up to 88 000 lbs., about 700 channels of strain gauge recording, and ancillary equipment for the testing of aircraft wings up to about 120 ft. span.

(5) Ancillary materials research equipment.

(6) Helicopter icing rig.

(7) Moving base simulator.

(8) Hydrodynamics equipment.

(9) Workshop equipment.

(10) The foregoing list of installations, facilities and equipment is backed up directly by a large amount of unlisted small tools, apparatus and measuring systems, and less directly by a substantial fraction of the total laboratory resources of the National Research Council, and having a replacement value of many millions of dollars.

Appendix 9

Some Current Aeronautical R & D Projects at the National Research Council Laboratories

Because of the length of the original list of projects submitted to the Study Committee, the ones actually cited in what follows have been selected to illustrate the breadth of the work being done and to indicate its relevance for the solution of manufacturing and operational problems. The projects themselves have been sponsored and financially supported by a wide variety of Canadian and foreign departments and agencies in both the public and private sectors, by individual industrial companies, and by groups of companies.

Program	Projects	Staff Effort: Man-Yr. per Yr.
Loads and Environmental Studies	Statistical recorders and acceleration counter installations:	1
	a) STOL aircraft operations b) Water bomber operations c) Military operations d) Agricultural aircraft and low altitude statistics. Analysis & evaluation of design load spectra.	$\frac{1}{2}$
Mechanics of Elements & Systems	Bird impact evaluations: a) Design & development of gun facility b) Comparative studies of strikes with real and simulated bird packages.	2
Fatigue	Evaluation of T-33 (<i>Tutor</i>) aircraft.	4
	Effect of load spectra and load sequence on airframe fatigue.	$1\frac{1}{2}$
	Influence of residual stresses on fatigue endurance.	$\frac{1}{2}$
	Fractographic techniques in failure analysis.	1
	Fatigue evaluation & clearance of Avian 180 gyroplane	2
	Numerical & experimental methods of fatigue life estimation.	$\frac{1}{2}$
Dynamics and Aeroelasticity	Application of finite element analysis to structural vibrations and aeroelastic response.	$\frac{1}{2}$
	Power spectral and random response analysis.	$\frac{1}{2}$
	Studies in the acoustic excitation of stringer-panel configurations.	$\frac{1}{2}$
Materials	Cyclic oxidation resistance of high temperature superalloy coatings.	1
	Deposition techniques and high temperature diffusion characteristics for chrome, titanium & silicon coating elements on niobium substrates.	2
Unscheduled Structural Investigations and Special Projects	Studies of accident phenomena and failure analysis.	$\frac{3}{4}$
	Investigation of airworthiness concepts and special requirements.	$\frac{1}{2}$

Program	Projects	Staff Effort: Man-Yr. per Yr.
Power Plants	<p>VTOL aircraft R & D projects with particular reference to propulsion systems and the requirements for reliability, economy and overall safety as related to possible Canadian air transportation requirements in the 1970s.</p> <p>Industrial and aircraft gas turbines.</p> <p>Dynamics of highly loaded gearing.</p> <p>De-icing and anti-icing measures.</p> <p>Bird collisions along airways and around airports.</p> <p>Noise suppression of high-powered jet engines.</p> <p>Fuels & lubricants.</p>	<p>6½</p> <p>7½</p> <p>2</p> <p>3</p> <p>4½</p> <p>1</p> <p>3½</p>
Aircraft Performance & Handling	<p>Four-degree-of-freedom airborne simulator:</p> <p>a) v/STOL lateral-directional flying qualities</p> <p>b) Non-linear lateral handling qualities & investigation</p> <p>c) Simulator feel system development</p> <p>d) CL-84 simulation training for Canadian Forces pilots.</p> <p>Six-degree-of-freedom airborne simulator proposal.</p> <p>Other lateral handling qualities for simulation validation.</p>	<p>4 for all the projects in this category</p>
Atmospheric Studies	<p>Atmospheric turbulence research:</p> <p>a) Clear air turbulence</p> <p>b) Turbulence in and near thunderstorms</p> <p>c) Infrared techniques for CAT-detection</p> <p>d) Low altitude & approach turbulence</p> <p>e) Wind field measurements near thunderstorms.</p> <p>High-altitude turbulence encounters.</p>	<p>3</p> <p>½</p>
Aircraft Operational Techniques & Studies	<p>Fire bombing:</p> <p>a) Theoretical models of liquid break-up and pattern</p> <p>b) Evaluation of ground patterns for various fire-bombing aircraft</p> <p>c) Investigation of aircraft pitch-up during liquid drop.</p> <p>Forestry & agricultural aircraft operation:</p> <p>a) Radar altimeter evaluation</p> <p>b) Spray equipment development.</p> <p>v/STOL aircraft potentialities—assessment of proposals.</p> <p>Aircraft vortex wake investigations.</p>	<p>1</p> <p>5 for the latter three projects in this category</p>

Program	Projects	Staff Effort: Man-Yr. per Yr.
Aircraft Accident/Incident Detection & Investigation	NRC crash position indicator: a) CPI for helicopters b) CPI for fixed-wing aircraft—range testing & other services to industry. Aircraft accidents, interpretation of tech- nical data and evidence & data recorder requirements & evaluation.	1 1
Trisonic Wind Tunnel Tests for the Aviation Industry and Government Agencies	Effects of body flexibility on the static longitudinal stability of flight vehicles. Flutter feasibility tests on flexible swept- wing model. Wing panel load measurement on model of <i>Moby</i> underwater towed vehicle. High lift, high Reynolds number wing section tests. Airscrew tests at high advance ratios & high subsonic Mach numbers. Very high Reynolds number (full scale) wing section tests at transonic speeds.	1 $\frac{1}{4}$ $\frac{1}{4}$ $\frac{3}{4}$ $\frac{1}{2}$ $\frac{1}{2}$
High Lift, High Reynolds Number Aerodynamics	Tests on 18 in. chord two-dimensional section of augmentor wing at full scale Reynolds number for determining opti- mum approach & landing configurations. Development of theoretical methods of transonic wing section design for both subcritical and supercritical lifting con- ditions.	1 $\frac{1}{2}$ $\frac{3}{4}$
Theoretical and Experimen- tal Investigations of Three- Dimensional Flow Fields	Flow about upswept rear loading fuse- lages. Flow separation on long slender bodies of revolution at incidence. Internal flow in conical ducts. Theoretical studies of three-dimensional laminar boundary layers with suction & injection. Three-dimensional separation of turbu- lent boundary layers by oblique shock waves & control using blowing.	$\frac{1}{2}$ $\frac{1}{4}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$
Industrial Low Speed Wind Tunnel Testing	DHC-7; augmentor wing; high-lift aero- foils; CL-215.	3
Aerodynamics of v/STOL Aircraft	Tilt-wing slipstream interaction. High-lift wings, augmentor wing.	$\frac{1}{2}$ 1

Appendix 10

Summary of the Aeronautical R & D Capabilities of the National Research Council Laboratories

The following is a summary of the research capabilities at the National Research Council having relevance to aircraft design, testing, performance, or utilization in the existing Canadian context.

Aerodynamics

Major applied aerodynamic studies from low subsonic to Mach 4.5.

Aircraft Investigations—Conventional and V/STOL

Aerodynamic study of v/STOL aircraft problems.

Control: Human operator; Investigation of flying qualities; Simulators.

Investigation of slipstream deflection and high-lift devices.

Safety: Flight instrument performance; Investigations of bird hazards to aircraft. Transition aerodynamics.

Biological Engineering

Development of electronic instrumentation for physiological and behavioural studies. Engineering applications of living transducers.

Control Developments

Aids to navigation.

Man-machine optimization:

- Basic phenomena underlying tracking performance

- Psycho-physiological factors

- Sensory interaction

- Simulator validation and determination of factors affecting transfer of skill.

Engineering Production

Application of modern control theory and technology to the solution of industrial process control problems.

Automatic controls investigation.

Development of acceleration memory recorder.

Development of analog and digital program milling machine techniques.

Development of gas lubricated bearings.

Development of metal extrusion techniques.

Industrial plant development.

Machine tool development.

Man-machine communication in computer systems used in an engineering environment.

Statistical data processing of continuously recorded data.

The application of analog, digital and hybrid computers to the study of engineering systems.

Environmental Effects and Control*

Airframe and power plant icing.

Catalytic heaters for cold weather operations.

General cold weather environmental testing.

Precipitation physics.

Turbulence investigations in the atmosphere.

Noise research.

*NRC did a great deal of pioneering work on icing during and following World War II.

Fuels & Lubricants

Contaminants in fuels and lubricating oils.
Electrostatic charging during refuelling operations.
Examination of fuel additives.
Hydraulic brake fluid performance.
Instrument lubricants.
Lubricant performance under boundary conditions.
Methods of used oil analysis.
Performance evaluation of engine and gear oils and greases.
Synthetic and high dispersion lubricating oils.

National Defence

Fatigue testing of full-scale structures.
Qualification tests on military equipment and materials.
Aircraft performance analysis.
Helicopter crash position indicator.
Anti-submarine warfare.

Power Plants

Aerodynamic methods of augmenting static thrust.
Combustion studies for aero and industrial gas turbines.
Cycle analyses on gas turbine power plants.
Dynamic response of power plants.
Examination of centrifugal and axial compressors.
Heat transfer studies related to gas turbine operation.
Noise measurement and monitoring systems.
Study of coated refractory metal alloys.

Structural Investigations

Acoustic noise effects on structures.
Fatigue:
–Cumulative damage
–Crack propagation
–Maraging steel
–Thermal fatigue
–Structures and structural elements.
Non-destructive testing of bonded joints.
Standardization of accelerometers.
Undercarriage design, including aircraft skis.
Vibration analysis.

Materials

Mechanical properties of aircraft materials.
Dislocation theory.
Fractography.
Oxidation of metals.
Electrochemistry of corrosion.
Composite materials.

Avionics

Design of antennae.
Development of radar and navigational aids.

Library and Information Service

The library houses a selection of books, technical reports, periodicals, and reference tools in the following engineering fields:

- Aeronautical engineering
- Agricultural and forestry aviation
- Automatic control and computation
- Control systems and human engineering
- Low temperature research
- Mechanical engineering
- Metals and materials research.

The Library Information Service provides:
–Interlibrary loan service to industry, universities, and government departments of material not readily available elsewhere;
–Reference service in its specific fields of interest;
–Selective bibliographies compiled upon request;
–Semimonthly list of recent additions of books and technical reports to the library.

Appendix 11

Data for some Successful
Aeronautical Projects

The following information was included in Appendix II of the Brief submitted to the Aeronautical R & D Study Committee by the Air Industries Association of Canada.

Manufacturer	Product	Canadian Government Funding (\$ millions)	Orders Received (\$ millions)	Additional Forecast to 1975 (\$ millions)
The de Havilland Aircraft of Canada Ltd.	DHC-6 aircraft (<i>Twin Otter</i>)	3	130	270
Canadair Ltd.	CL-41 aircraft (<i>Jet Trainer</i>)	1½	67	75
United Aircraft of Canada Ltd.	PT-6 engine	15	163	613
CAE Ltd.	Flight Simulators	1½	23	60
Computing Devices of Canada Ltd.	Position and Homing Indicator	2/3	56	
Computing Devices of Canada Ltd.	Moving Map Display	1	9	
Aviation Electric Ltd.	Mechanical Ball Resolver	1/8	3½	1½
Canadair Ltd.	CL-89 Reconnaissance Drone	11	91	23

Appendix 12

Grant Support for Aeronautical Research in Canadian Universities

The information given in this Appendix refers to the academic year 1968-69. It refers, also, to two categories of replies to the survey questionnaires which were sent to the universities, namely:

Category (a): Work specifically in aeronautics;

Category (b): Projects with some application to aeronautics.

Table 1—Grant Support By Provinces: Categories (a) and (b)

Province	No. of Staff Involved	Value of Grants (\$ Rounded)	P.D.F. and Graduate Students
B.C.	7	79 000	14
Alberta	5	31 000	8
Saskatchewan	2	4 000	
Manitoba	2	16 000	6
Ontario*	44	937 000	155
Quebec†	16	309 000	54
Nova Scotia	1	49 000	6
Total	77	1 425 000	243

*The figures for the University of Toronto Institute for Aerospace Studies alone are: 14 staff; \$512 000 in value of work; and 70 postdoctorate fellows and graduate students.

†The figures for McGill University alone are: 9 staff; \$225 000 in value of work; and 39 postdoctorate fellows and graduate students.

Table 2—Grant Support By University: Category (a) Only

University	No. of Staff Involved	Value of Grants (\$ Rounded)	P.D.F. and Graduate Students
U.B.C.	2	32 000	7
U. of Alberta	2	17 000	6
U. of Calgary	2	4 000	
U. of Saskatchewan	1	2 000	
U. of Manitoba	2	16 000	6
Carleton U.	5	59 000	12
McMaster U.	1	17 000	1
UTIAS	11	433 000	56
U. of Toronto (except UTIAS)	2	13 000	10
U. of Waterloo	6	51 000	12
U. of Windsor	1	5 000	1
U. Laval	4	66 000	12
McGill	5	90 000	20
Total	44	805 000	143

Table 3–Supporting Agencies

Agency	Category (a) (\$ Rounded)	Category (b) (\$ Rounded)
National Research Council (NRC)	427 000	267 000
Defence Research Board (DRB)	144 000	88 000
Dept. of Defence Production (DDP)		7 000
Dept. of Transport (DOT)		53 000
Medical Research Council (MRC)		5 000
Industry (Ind.)		80 000
Dept. of University Affairs, Ontario (DUA)	6 000	15 000
Alberta Research Council (ARC)		10 000
U.S. National Aeronautics & Space Admin. (NASA)	30 000	
NASA /U.S. DOT		20 000
United States Air Force (USAF)		11 000
USAF/Research & Technology (USAF/RTD)	20 000	
U.S. Air Force Office of Scientific Research (AFOSR)	58 000	34 000
U.S. Office of Naval Research (ONR)	19 000	
U.S. Environmental Science Services Admin. (ESSA)		20 000
U.S. Aerospace Research Laboratories (ARL)	85 000	
U.S. Space Research Institute (SRI)	15 000	
American Iron & Steel Institute (AISI)		11 000
Boeing Aircraft Corporation		1 000
Total	804 000	622 000

Table 4–Supporting Agencies for University of Toronto Institute for Aerospace Studies and for McGill University

Agency	Category (a) (\$ Rounded)	Category (b) (\$ Rounded)
<i>UTIAS:</i>		
NRC	174 000	30 000
DRB	45 000	14 000
USAF/RTD	20 000	
AFOSR	58 000	34 000
ONR	19 000	
NASA	30 000	
ARL	85 000	
DUA	2 000	2 000
Total	433 000	80 000
<i>McGill:</i>		
NRC	30 000	55 000
DRB	45 000	
SRI	15 000	
ESSA		20 000
DOT		50 000
ARC		10 000
Total	90 000	135 000

Appendix 13

Government Advisory Bodies and their Constitutions

Although the constitutions and terms of reference quoted in this Appendix are the last ones to have been formulated, they do not take into account the most recent changes in the organization and structure of the federal government. But the NARC, for example, has not met since these changes were made and has not had the opportunity to request amendments to its constitution. These amendments have not been assumed in what follows. Instead, asterisks have been added in those places in which amendments will most likely be required. Non-government title amendments have, however, been made where appropriate.

The National Aeronautical Research Committee

The following is the current formal *Constitution* of the NARC:

1. Name

The formation of the National Aeronautical Research Committee was authorized by Cabinet directive in December 1950. The Committee shall report to the Privy Council Committee on Scientific and Industrial Research*, except that on matters relating to defence, it shall report also to the Cabinet Defence Committee*.

2. Terms of Reference

- a) The NARC shall be responsible for the overall advice on government policy on Aeronautical Research in Canada.
- b) The NARC shall:
 - (i) Consider the reports and recommendations of the Technical Advisory Panel with regard to Canadian research requirements and facilities;
 - (ii) Consider Canadian research programs and their relation to the national need;
 - (iii) Endorse the implementation of approved proposals for new or re-oriented research programs, for new research facilities, or for industrial participation of appropriate kind.
- c) The NARC will also review research programs inside and outside the government service with a view to achieving the best possible co-ordination.

3. Membership

The membership of the National Aeronautical Research Committee shall consist of: President, National Research Council; Chairman, Defence Research Board; Chief of the Air Staff, RCAF*; Deputy Minister, Department of Defence Production*; Deputy Minister, Department of Transport.

4. Chairman

The Committee shall choose one of its members to act as Chairman. The term of office of the Chairman will be two years.

5. Secretary

The Secretary of the Committee will be provided from the staff of the Defence Research Board or the National Research Council.

6. Meetings

The Committee shall meet at the call of the Chairman, and there shall be at least one meeting annually.

The Technical Advisory Panel

1. Name

A Panel is hereby constituted to be known as the Technical Advisory Panel of the National Aeronautical Research Committee.

2. Terms of Reference

The Technical Advisory Panel will advise the National Aeronautical Research Committee on all technical matters involving policy and will serve as a scientific and technical advisory panel to the Director of the (National Aeronautical) Establishment. Among other duties which might be assigned by the National Aeronautical Research Committee, the Technical Advisory Panel will be required:

a) To establish or recommend the establishment of such advisory committees as may seem desirable;

b) To review at least annually the aeronautical research programs already in existence in or sponsored by the agencies participating in NARC as well as those programs in existence elsewhere in Canada. Account will also be taken of programs active in other countries.

c) To review the reports submitted by the advisory committees.

d) To review at least annually the requirements for aeronautical research.

e) Following the above reviews, to recommend to NARC programs which will help to overcome the deficiencies between the research requirements and research in existence or which may seem desirable for some other purpose.

3. Membership

The membership of the Technical Advisory Panel shall consist of:
Vice President, (Scientific), National Research Council;
Chief Scientist, Defence Research Board;
Chief Aeronautical Engineer, Department of Transport;
Air Member for Technical Services, RCAF*;
Director, Aircraft Branch, Department of Defence Production*;
Director of the National Aeronautical Establishment;
Director of Engineering, Defence Research Board;
Director, Division of Mechanical Engineering, NRC;
Director, University of Toronto Institute for Aerospace Studies;

One member, appointed by the Canadian Armament Research & Development Establishment*;
Two members, appointed by the Air Industries & Air Transport Associations of Canada.

4. Chairman

The Chairman shall be appointed from the membership of the Panel by the National Aeronautical Research Committee.

5. Secretary

The Secretary of the Panel shall be provided from the staff of the National Aeronautical Establishment.

6. Meetings

The Panel shall meet at the call of the Chairman, and there shall be at least one meeting annually.

Terms of Reference of Associate Committees

Within the commonly accepted bounds of the subject connoted by the title of the Associate Committee and with respect to both aeronautical and astronautical interests, the Committee is invited:

1. To consider Canadian pure and applied research needs and to make recommendations to the Technical Advisory Panel of the National Aeronautical Research Committee for appropriate programs.

2. To consider the provision of facilities for the proper support of Canadian research and to make appropriate recommendations to the Technical Advisory Panel to create and maintain these facilities.

3. To consider the work of the Commonwealth Advisory Aeronautical Research Council and the Advisory Group for Aeronautical Research & Development of the North Atlantic Treaty Organization and to recommend to the Technical Advisory Panel appropriate policy and action.

It is also proposed:

- A. That the Associate Committees shall meet not less than twice per year.

- B. That appointments to the Committees shall be for a term of two years subject to re-appointment.

Appendix 14

Extracts from the Brief Submitted by the Technical Advisory Panel and Dealing with Future Programs of Aeronautical R & D

These extracts have been taken from pages 4 to 8, inclusive, of the Technical Advisory Panel's brief. The project areas, symbol definitions, and pertinence coding were established by the Panel and do not necessarily reflect the views of the Science Council Study Committee. The extracts are as follows:

Reports received from the various Associate Committees and the contributions from DOT and DND have yielded a large number of individual research projects, all of which are considered by each Committee or agency as essential in the field in which that particular Committee or agency is active. These are listed below in abbreviated form as they were received, and not in any order of priority.

The coding associated with each project area is an assessment by the Technical Advisory Panel of the pertinence of the area to the Canadian economy and society. The degree of pertinence represented by the coding has been derived from the following symbol definitions:

A: Short-term economic considerations

B: Long-term economic considerations

C: Social considerations

1: Highly significant

2: Less highly significant

3: Still less highly significant

For example, a project area coded A2-B1-C3 is to be interpreted as being highly significant in the long-term economic view with less short-term economic significance, and of relatively little significance in terms of the social considerations.

	Pertinence Coding
Aerodynamics	
VTOL and STOL aircraft interactions of propulsion and lift aerodynamics.	A2-B1-C1
v/STOL flying qualities, stability augmentation, and the use of moving and fixed-base simulators.	A2-B1-C1
Steady and unsteady aerodynamics associated with separated flow.	A2-B2-C3
Flight in low-level turbulence, theoretical investigation of response of a non-linear vehicle system with variable aerodynamic coefficients.	A2-B1-C3
Aerospace Systems	
Multiple-redundant systems.	A2-B2-C3
Mechanical systems, gearboxes, actuators, and load-limiting devices.	A3-B3-C3
Materials development, high-strength steels and composites.	A3-B1-C2
Landing gears, development of new energy-absorption concepts.	A3-B2-C3
Linear and rotary hydraulic actuators.	A3-B3-C3
High-pressure and high-temperature hydraulic systems.	A3-B1-C3
Fluidic devices, interfacing with conventional hydraulic systems.	A1-B2-C3
Pulsating-flow hydraulic systems.	A3-B2-C3
Generation of design data peculiar to aerospace control equipment, for example, fail-safe concepts and system optimization.	A3-B2-C2
Improvements in aircraft/crew survivability in crash and combat environments.	A2-B1-C2
Specific areas in development of fly-by-wire systems.	A1-B3-C3
Use of composites in system components.	A3-B2-C2
Avionics	
Natural resources development and management, remote-sensing systems.	A2-B1-C1
ASW equipment, dependent upon continuation of defence policy.	A2-B1-C3
Equipment for v/STOL operations, the emphasis being on the total system.	A2-B1-C1
Bird Hazards to Aircraft	
Bird dispersion methods, falconry, distress calls, noise-makers.	A2-B3-C2
Ecological surveys directed toward making airports less attractive to bird populations.	A1-B3-C2
Effects of microwave radiation.	A3-B1-C1
Radar detection of large-scale migrations.	A1-B3-C3
Biological identification of bird remnants following a strike, particularly important in identifying the cause of engine failure.	A2-B2-C2
Propulsion	
v/STOL propulsion systems, lightweight turbine engines for shaft power, lift augmentation, and direct lift.	A2-B1-C1
Small- and medium-thrust engines for subsonic commercial and military applications.	A2-B1-C1
Advances in engine design leading to development of engines for small supersonic aircraft.	A3-B3-C3
Limited involvement in the development of materials, fuels and combustion processes for hypersonic applications.	A3-B3-C3
Systems engineering, safety and reliability, cost and production methods.	A1-B1-C1
Noise and pollution control.	A3-B3-C1
Fuel controls and fuel-control systems.	A3-B3-C3
Aerodynamics of turbomachinery.	A3-B2-C2
Heat transfer and cooling.	A3-B2-C2
Fuels and combustion processes.	A3-B2-C3
Mechanical design, power transmission systems, materials development.	A3-B2-C3
Mechanical and aerodynamic design of propellers.	A3-B1-C2

	Pertinence Coding
Aircraft Structures and Materials	
Operational and environmental loading actions on aircraft, particularly studies of low-level turbulence and manoeuvre loads, runway response, and intense noise loadings.	A1-B1-C3
Damage and fatigue studies.	A1-B1-C3
Structural analysis, numerical techniques and structural optimization.	A2-B2-C3
Structural dynamics, power spectral methods.	A2-B2-C3
Bird-strike resistant engine and airframe components.	A2-B1-C2
Materials and environmental effects.	A3-B1-C3
Composites.	A3-B1-C2
Aviation Medicine and Human Engineering	
Instrument displays and information presentation.	A2-B1-C3
Psychological factors in aircrew selection and training methods.	A3-B2-C3
Improvement of medical standards and practices, particularly in the detection of visual and cardiac deficiencies.	A3-B2-C3
Investigation of psychological stress factors and aircrew performance.	A3-B1-C2
Problems associated with high-altitude and high-acceleration flight conditions.	A2-B2-C3
Biochemical methods in accident investigation, determination of psychological stress levels to which aircrew were subjected.	A3-B2-C3
Operational Problems	
Flying qualities, particularly stability and control in all areas of the flight envelope.	A1-B1-C1
Problems associated with approach and landing with particular reference to blind-landing systems.	A2-B1-C1
Flight simulators, both airborne and ground-based.	A1-B1-C1
Maintenance reliability and trend forecasting.	A3-B2-C3

Considering many of the projects listed above, research work has been in progress for some time, and will inevitably continue. Such work is, of course, essential in order to keep abreast of rapidly advancing technologies.

It will be obvious from examination of the various research projects listed that there is some duplication and a considerable degree of interdependence. It should also be realized that there are benefits to be gained which will be applicable in other fields not directly connected with the aerospace industry.

Publications of the Science Council of Canada

Annual Reports

- First Annual Report, 1966-67 (SS1-1967).
Second Annual Report, 1967-68 (SS1-1968).
Third Annual Report, 1968-69 (SS1-1969).
Annual Report, 1969-70 (SS1-1970).

Reports

- Report No. 1, A Space Program for Canada (SS22-1967/1, \$0.75).
Report No. 2, The Proposal for an Intense Neutron Generator: Initial Assessment and Recommendations (SS22-1967/2, \$0.25).
Report No. 3, A Major Program of Water Resources Research in Canada (SS22-1968/3, \$0.75).
Report No. 4, Towards a National Science Policy for Canada (SS22-1968/4, \$0.75).
Report No. 5, University Research and the Federal Government (SS22-1969/5, \$0.75).
Report No. 6, A Policy for Scientific and Technical Information Dissemination (SS22-1969/6, \$0.75).
Report No. 7, Earth Sciences Serving the Nation—Recommendations (SS-1970/7, \$0.75).

Special Studies

The first five of the series were published under the auspices of the Science Secretariat.

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Special Study No. 2, Physics in Canada: Survey and Outlook, by a Study Group of the Association of Physicists headed by D. C. Rose (SS21-1/2, \$2.50).

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Special Study No. 10, Agricultural Science in Canada, by B. N. Smallman, D. A. Chant, D. M. Connor, J. C. Gilson, A. E. Hannah, D. N. Huntley, E. Mercier, and M. Shaw. (SS21-1/10, \$2.00).